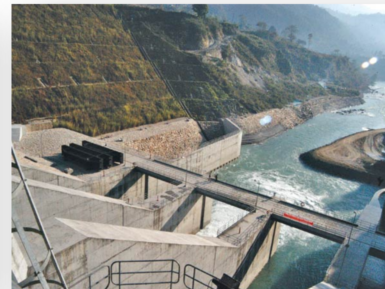
東京大学 THE UNIVERSITY OF TOKYO

IR3S

3ENexus

International Workshop: **Energy, Environment and Ecosystems (3E) Nexus**
Initiative for Sustainable Development in Asian Countries
26-27 February 2015, Bali, Indonesia






# Energy Engineering Education and R&D at Institute of Engineering, Tribhuvan University


**Prof. Tri Ratna Bajracharya, Ph.D.**
**Dean**
**Institute of Engineering, Tribhuvan University**
**Nepal**

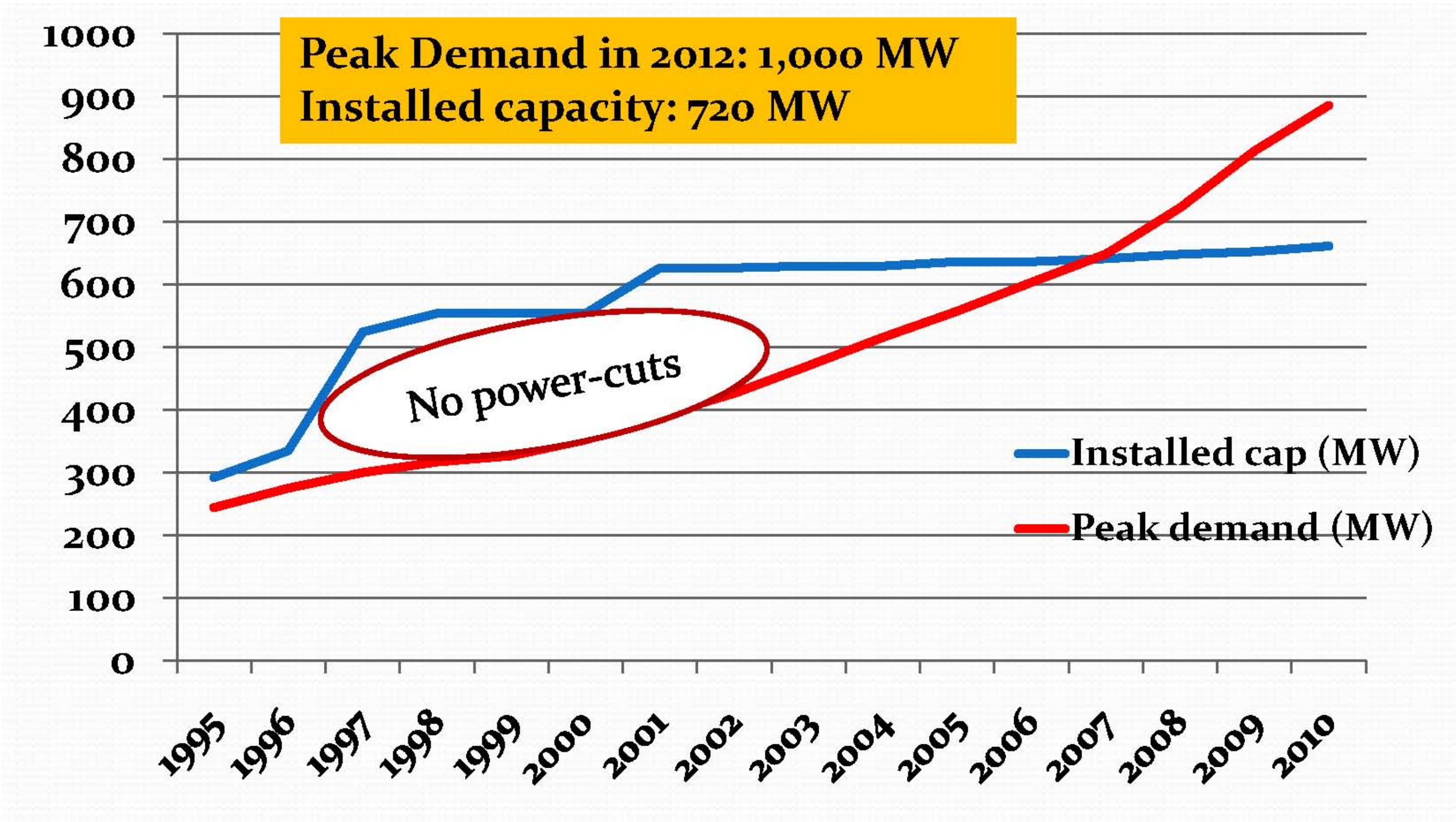
# Background

**Energy/Hydropower Potential**

- About 6,000 rivers, with a total length of about 45,000 km with an annual discharge of 200 billion cubic meters of water are available in the country
- The potential of hydro-power in Nepal is said to be about **83,000 MW**.
- So far only about 750 MW have been connected to peak load system, which constitute about 2% of total energy supply

# Power Capacity versus peak load

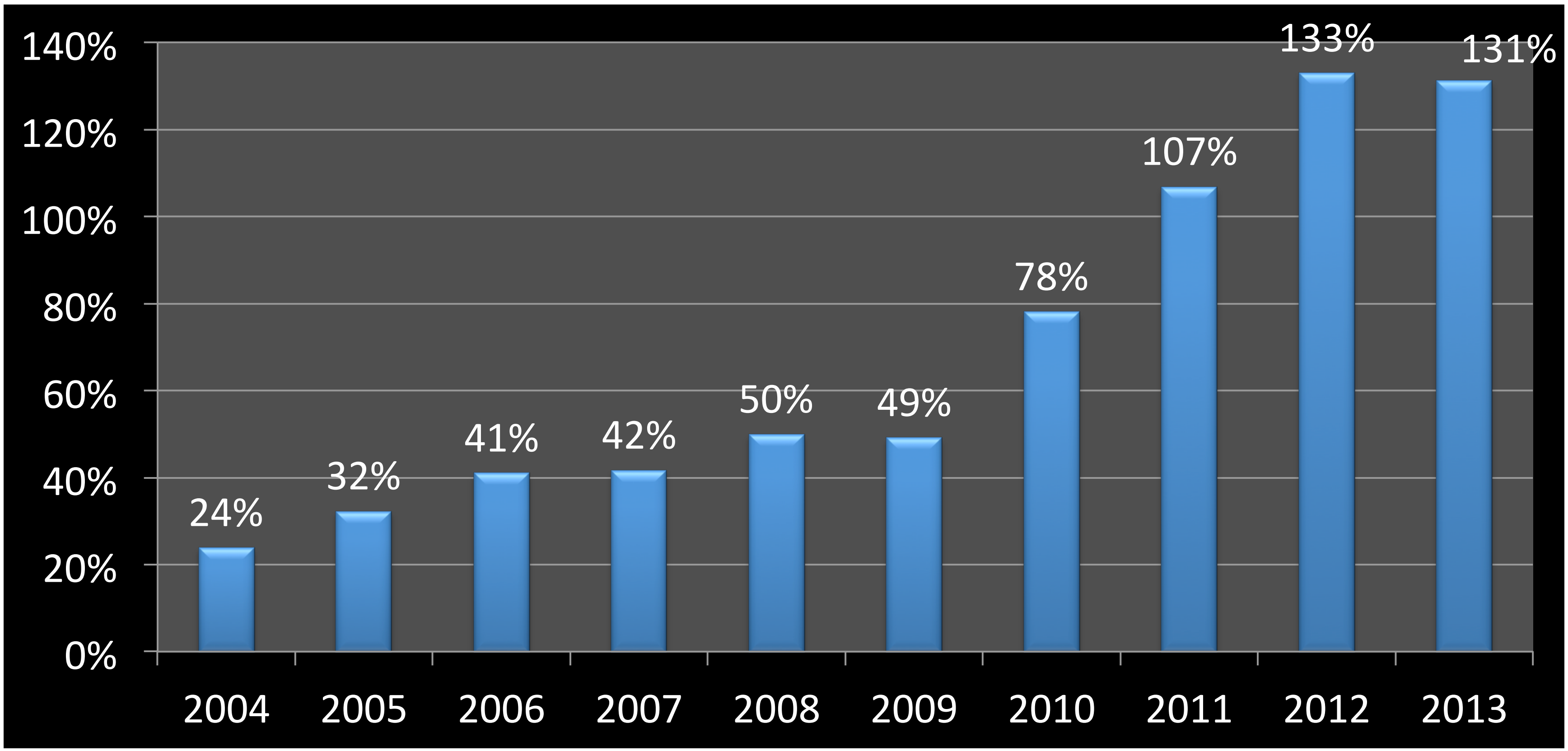
## Power capacity development: historical trend




Source: NEA (2012), Slide courtesy Prof. A.M. Nakarmi, CES

# Fossil Fuel

## Import of Petroleum Products against Commodity Exports

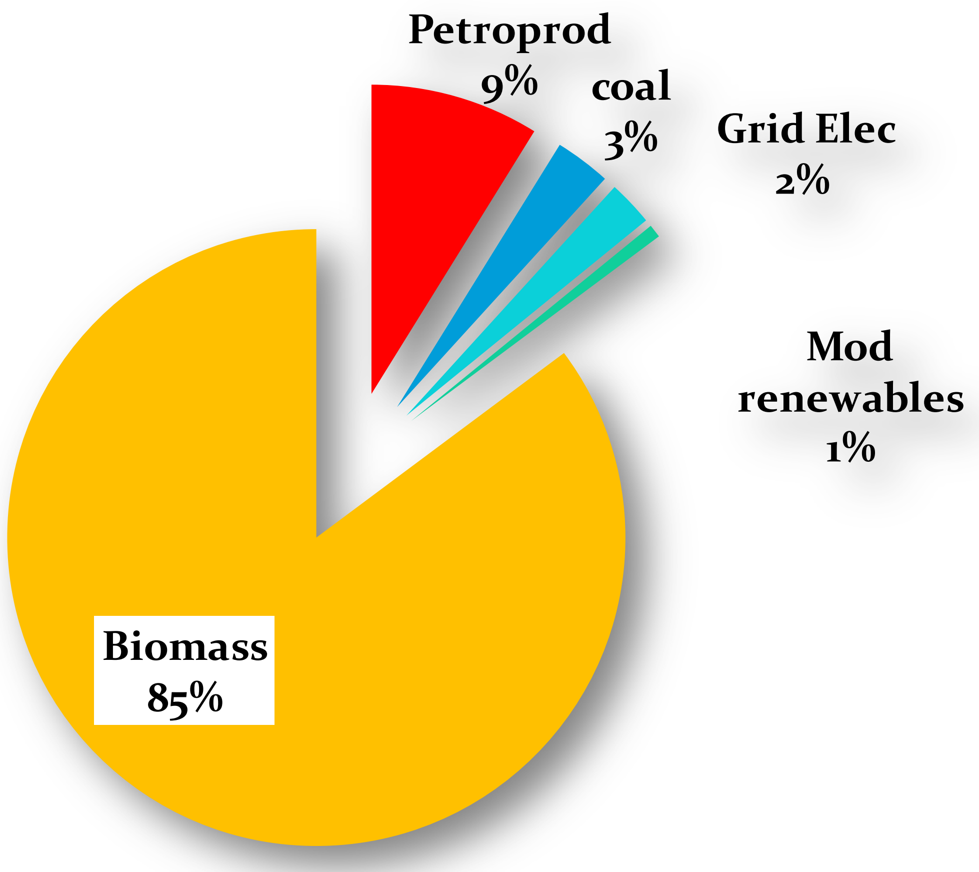



- **Economic Vulnerability increasing**

(Source: MOF, 2013; NOC, 2014)

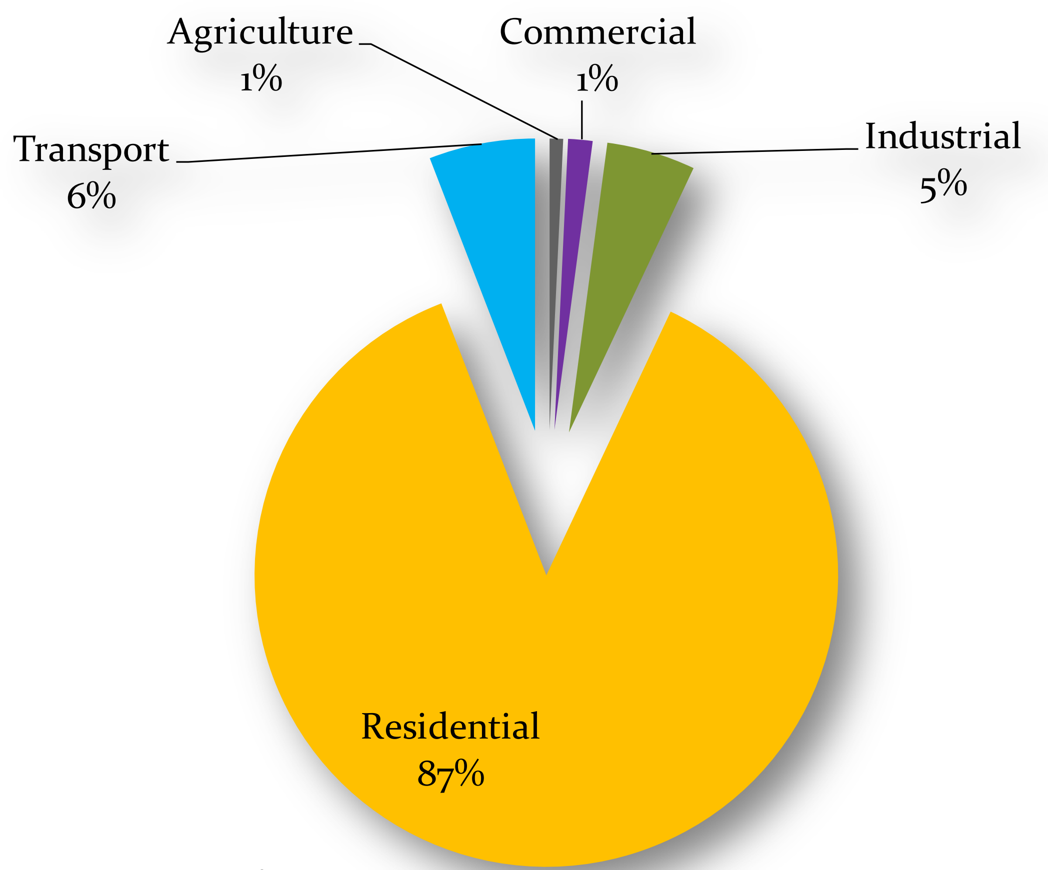
Slide courtesy Prof. A.M. Nakarmi, CES

# Overview of Energy Sector




Mix by Fuel type in 2010 (MOF, 2012; WECS, 2010)

# Energy consumption by Economic Sectors




(MOF, 2012; WECS, 2010)

# Engineering Education at TU

- Tribhuvan University (TU) was organized in 1954 & incorporated in 1959
- TU expanded to the span of the country
- TU delivers services through 5 Institutes, 4 faculties, research centers, etc.
- TU has 60 constituent campuses and 1100 affiliated colleges
- TU caters about 91% of the students (500,000 nos.) in higher education in the country.
- TU has about 8000 faculties and 7000 staffs
- **Institute of Engineering (IOE)** is catering about 15000 students

# Program and Courses at IOE

**IOE offers Ph.D. research, Master degree (graduate course), Bachelor degree (undergraduate course) in different engineering disciplines through campuses and colleges**

**Ph.D. Research**

Ph.D. Research is undergoing in all departments (civil , mechanical, electronics & computer, electrical, architecture & urban planning, science & humanities)

Energy Related Masters Programs

- Masters of Science in Water Resources Engineering
- Masters of Science in Renewable Energy Engineering
- Masters of Science in Energy Systems Planning and Management
- Masters of Science in Climate Change
- Masters of Science in Power Systems Engineering
- Masters of Science in Disasters Risks Management

# RESEARCH CENTRES

# Centre for Energy Studies
# (Zero Energy House)

**Established 1999**

- ❑Facilitates Masters and Ph.D. Courses
- ❑Conduct Technical Research
- ❑Conduct Policy Research
- ❑Organize Training Programs
- ❑Organize International Conferences
- ❑Provide consultancy to local and international

# Centre for Applied Research and Development (CARD)

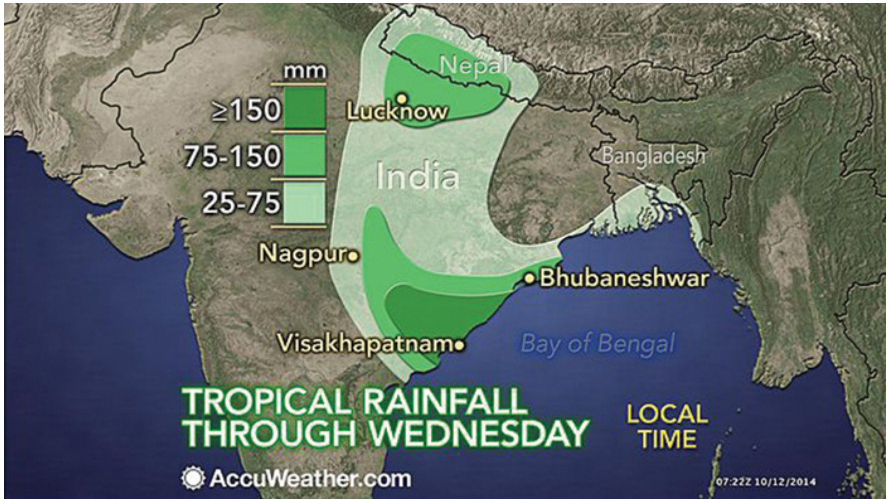
**Established 1996**

- ❑Establish International Cooperation for joint research
- ❑ Facilitate Advanced Academic Course
- ❑Conduct International Conferences

# Centre for Disaster Studies (CDS)

**Established 2002**

- Facilitates Masters and Ph.D. Courses
- Conduct Technical Research
- Conduct Policy Research
- Organize Training Programs
- Organize International Conferences
- Provide consultancies local and international




**DISASTROUS AUTUMN: The storm came in October, when locals and trekkers least expected it.**


Indian and Nepal meteorological offices had been warning about heavy precipitation from the remnants of Cyclone Hudhud as it veered north towards Nepal ever since it made landfall on 12 October. International tv channels warned of heavy rain in western and central Nepal. Two days before the storm arrived, Nepali media had warned farmers to protect their harvests.

# Newly Established Research Centres

- Centre for Urban Studies (CUS)
- Centre for Infrastructure Development Studies (CIDS)

# RECENT RESEARCH ACTIVITIES

## Atmospheric Science group at Department of Engineering Science and Humanities, Pulchowk Campus

Research on Solar Energy

- A high quality network of four solar radiation measurements (total solar radiation and UV measurements) in the Himalaya region has been established. Investigating potential use of solar energy (working to develop solar radiation maps)
- Established air pollution measurement laboratory at an urban station in Kathmandu.
- Study effects of altitude, aerosols (pollution), ozone and albedo on UV radiation.
- Validation of satellite UV radiation data at high altitudes with ground based data from the ground based network.
- Validation of UV index forecast models in high mountain area.

# Atmospheric Science group at Department of Engineering Science and Humanities, Pulchowk Campus

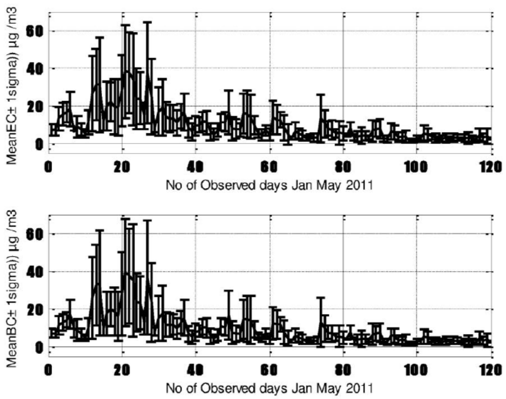



Figure 5: Daily average EC and BC concentration from January to May 2011at Biratnagar

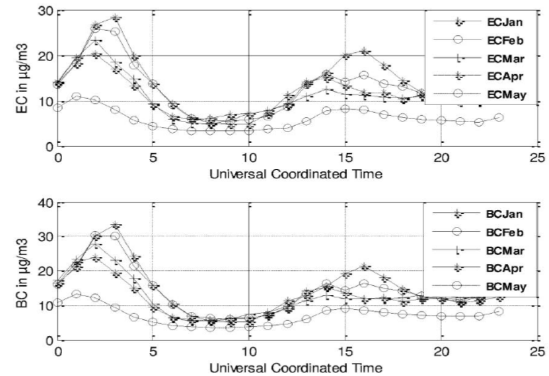



Figure 8: Diurnal Variations of EC and BC in Kathmandu from January to May

Air Pollution measurements data

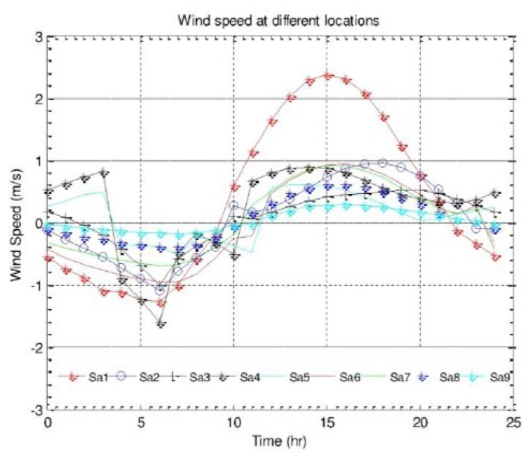



**Fig. 4:** Diurnal variation of wind speed above 10m form the surface at the different sampling sites where negative wind represents land breeze and positive wind speed represents sea breeze.

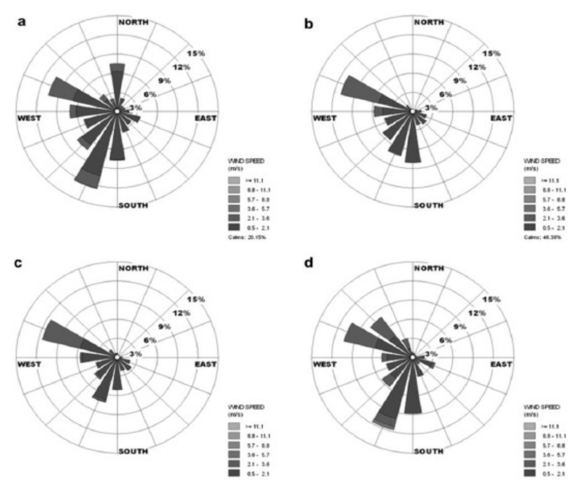



**Fig. 5.** Wind rose for Monsoon, Post-monsoon, winter and Pre-monsoon (a, b, c & d) to represent wind speed and direction.

Wind measurements data

# Atmospheric Science group at Department of Engineering Science and Humanities, Pulchowk Campus

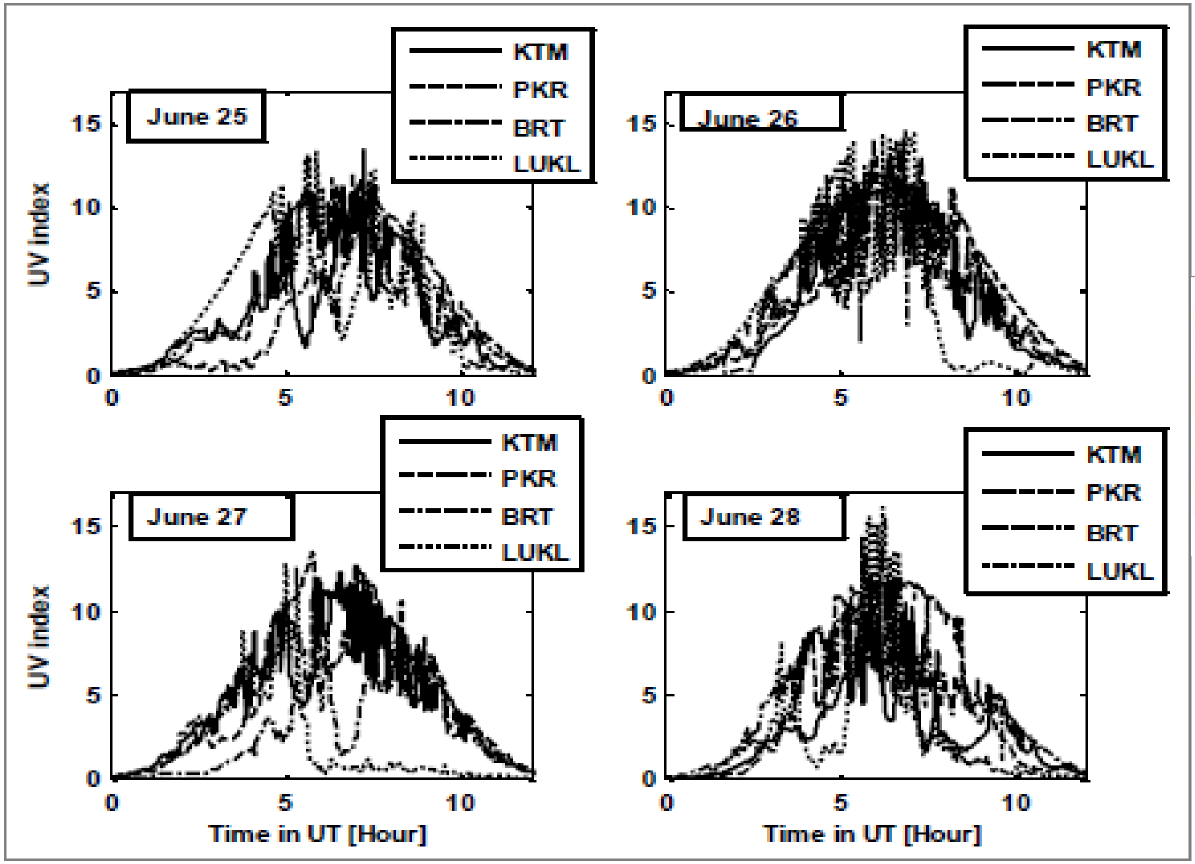



Figure 5.6: Daily averaged UV Index plots for 2010
in Kathmandu, Pokhara, Biratnagar and Lukla


UV radiation measurements data

# Researches at Centre for Energy Studies

## Building Integrated 6.5 kW PV system at CES


# Solar PV Grid Integration Research: 1 kW Grid Integrated PV Power at CES

P1 Location:
Pulchowk Campus, TU, CES/IOE
**with** load shedding, **without** backup system

# Researches at Centre for Energy Studies

## Research on Grid Integrated Net Metering for Nepal

### P2 Location: Min Bhawan NEA Office

**without** load shedding, **without** backup system

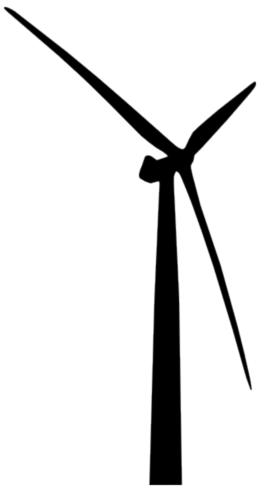
3 PV systems with same type of module and 3 different inverters

# Researches at Centre for Energy Studies

Provided Technical Support during installation of
TU Central Library 22 kWp PV Power Supply System 22 Nov 2012
(275*80PV M;2V 800 Ah*120)



# Solar and Wind Energy Resource Assessment (SWERA)



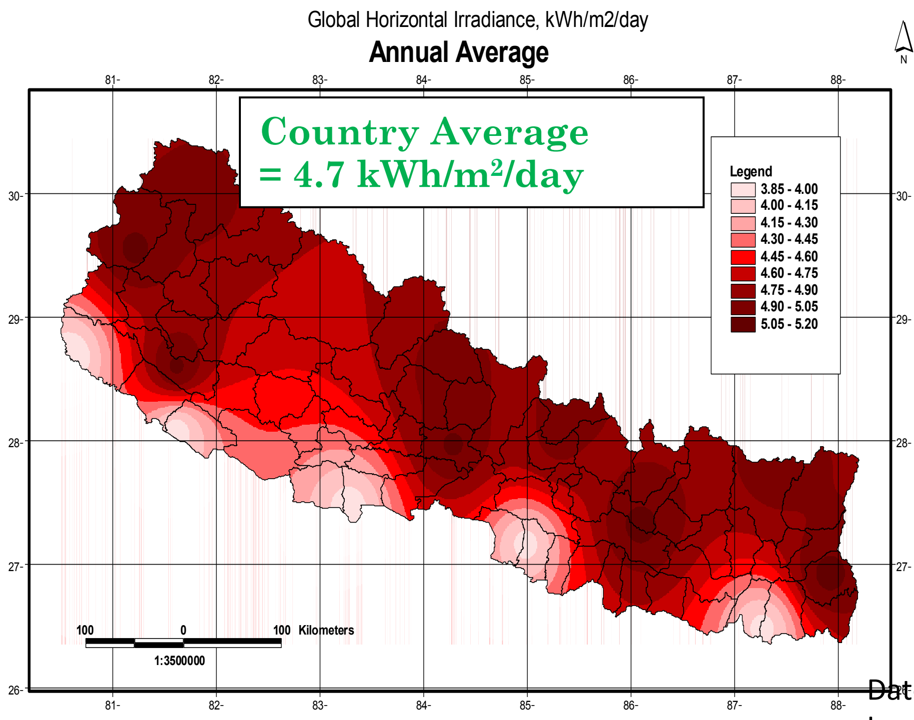
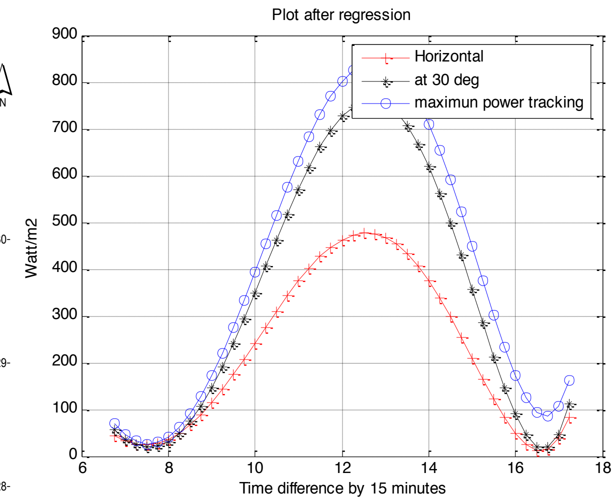



Figure 1

SWERA Project
Center for Energy Studies
Institute of Engineering, Tribhuvan University




Date: 2068/08/03, cloudy day
Location: CES Building (Latitude: 27°41′0″N(27.683°N) Longitude: 85°19′14″E(85.321°E)
Sun Rise: 6:45am, Sun Set: 5:07pm

**Around 300 days Sunshine**

Solar Energy is one of the best alternatives for Nepal.

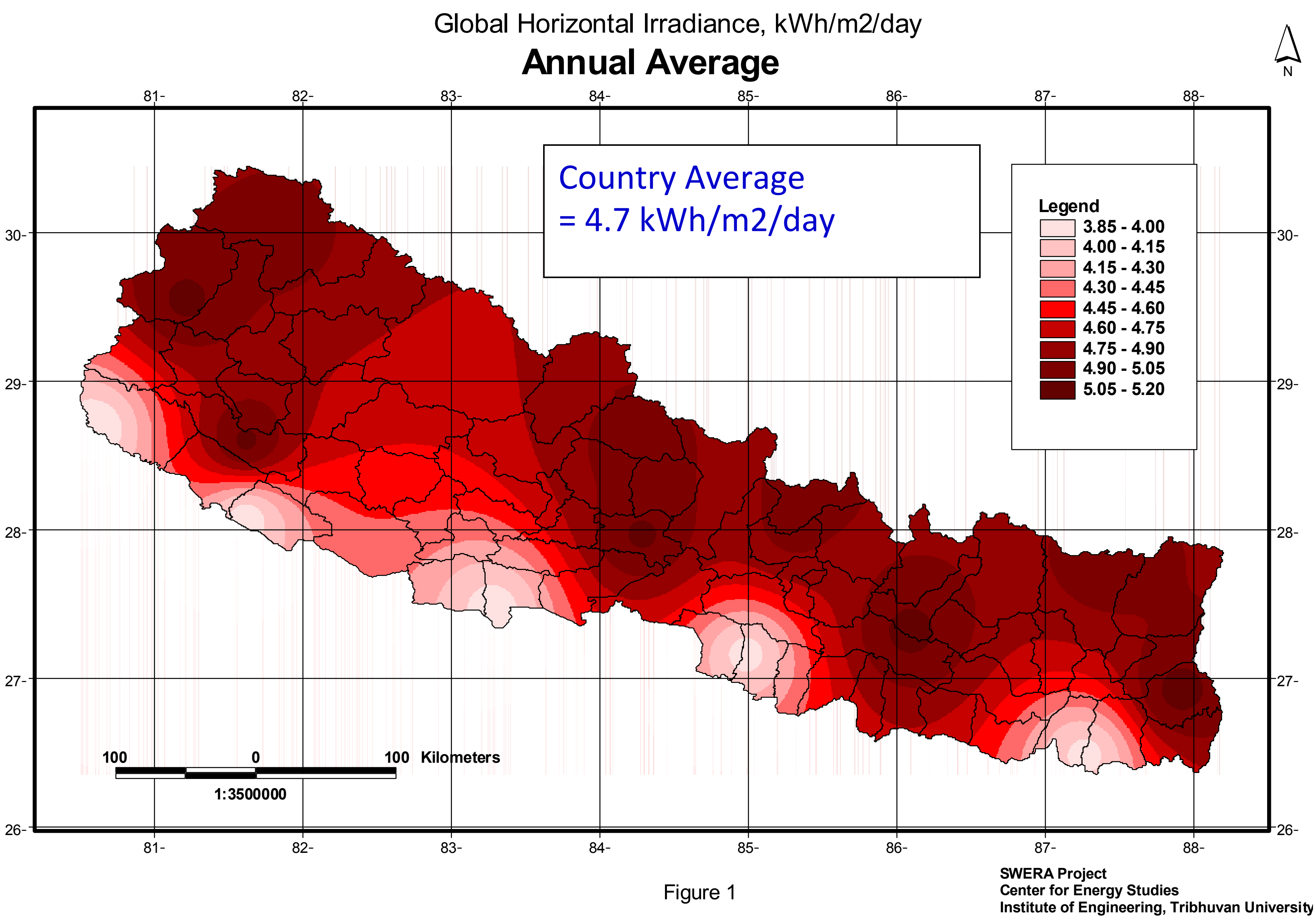
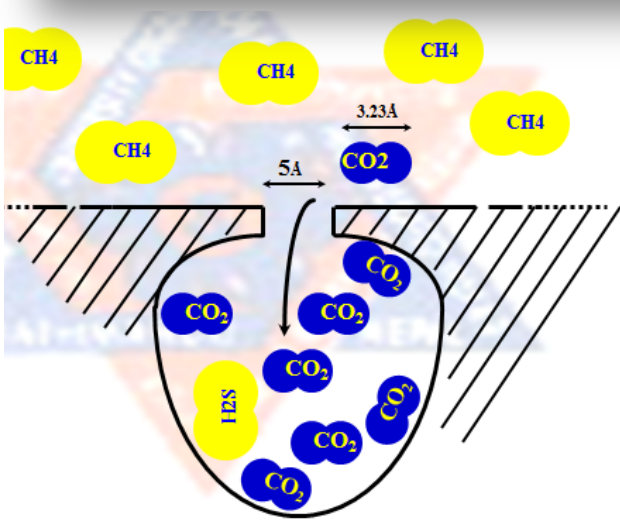
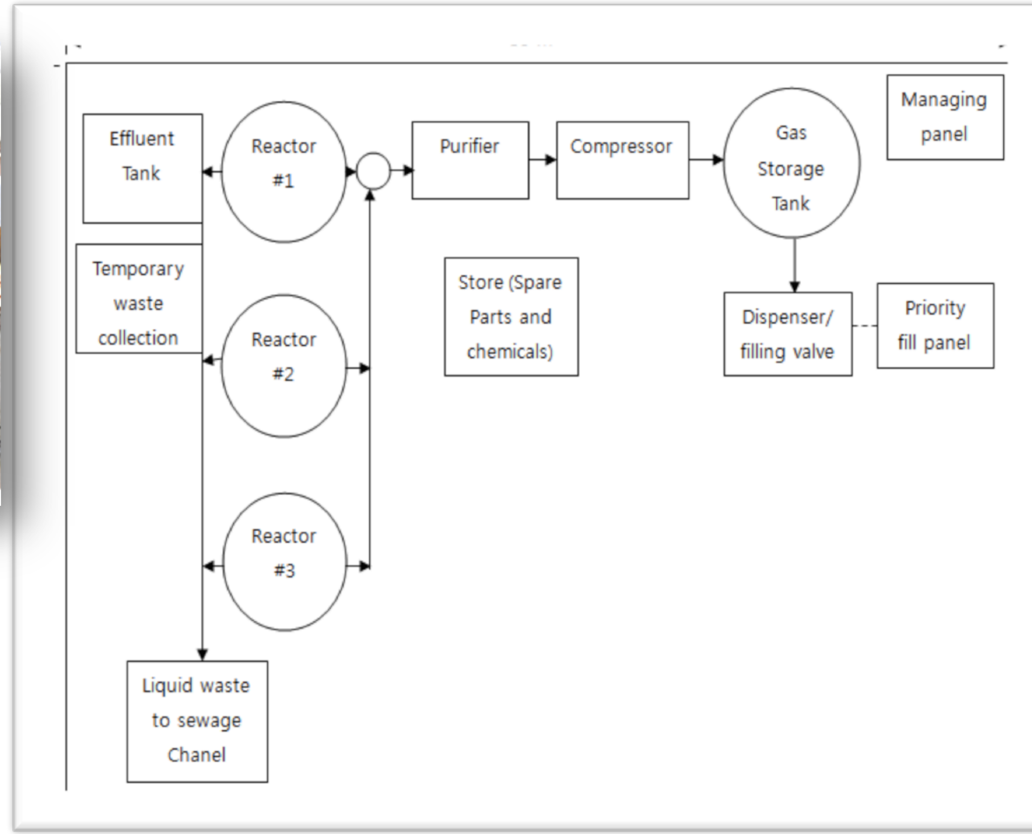

Global Horizontal Irradiance, kWh/m2/day
Annual Average
N
81-
82-
83-
84-
85-
86-
87-
88-
30-
29-
28-
27-
26-
Country Average
= 4.7 kWh/m2/day
Legend
3.85 - 4.00
4.00 - 4.15
4.15 - 4.30
4.30 - 4.45
4.45 - 4.60
4.60 - 4.75
4.75 - 4.90
4.90 - 5.05
5.05 - 5.20
100
0
100 Kilometers
1:3500000
SWERA Project
Center for Energy Studies
Institute of Engineering, Tribhuvan University

Figure 1

# Biogas

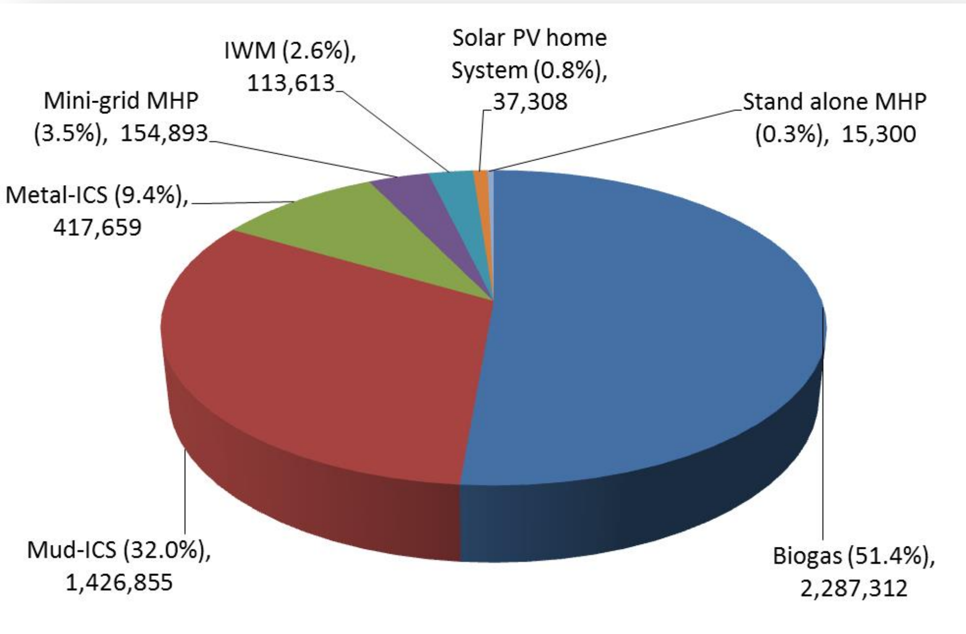
## Purification of Biogas by Pressure Swing Absorption Method to produce CNG

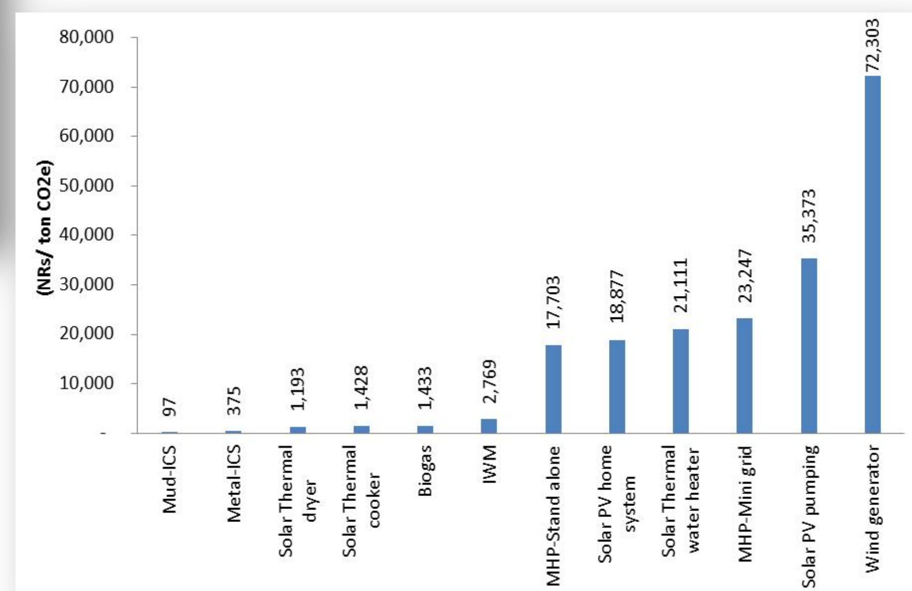



Climate Change

# Study on Role of Renewable Energy Technologies in Climate Change Mitigation and Adaptation Options in Nepal

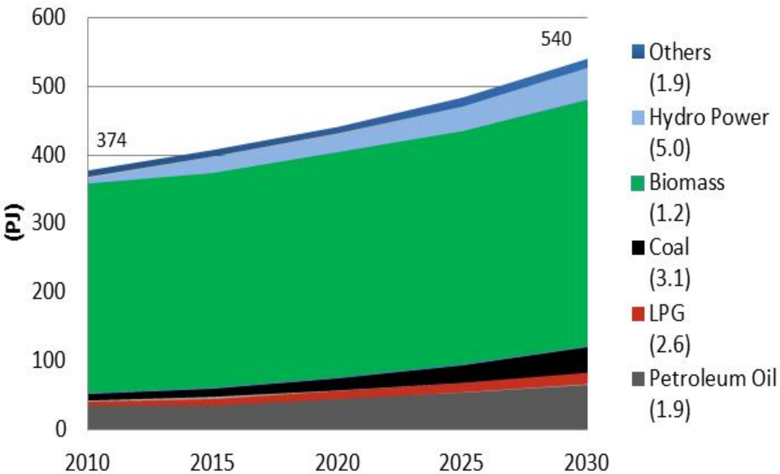


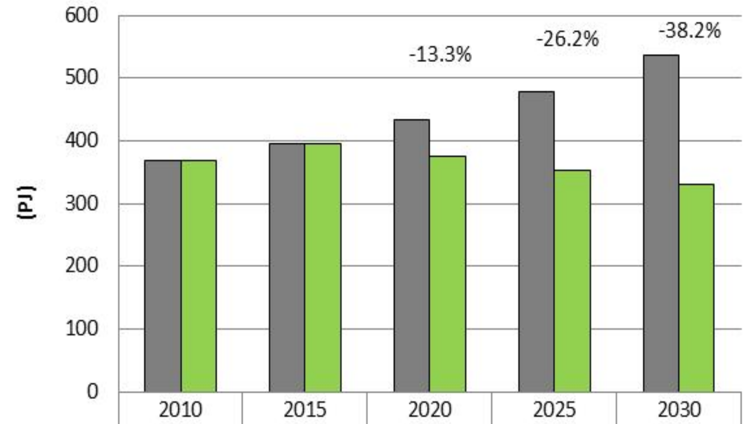

*GHG Mitigation Potential of Renewable Energy Technologies in Nepal, ton CO2e*
*(4.45 million tons of CO2e per year and 30.71 million tons of $CO_2$e can be mitigated between the periods of 2013 to 2030)*



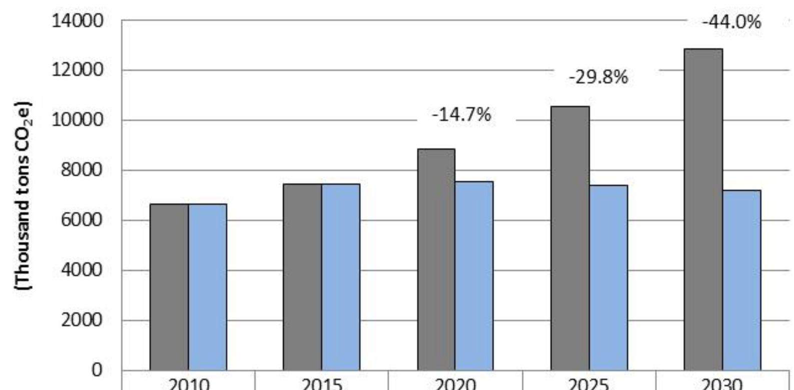

*Annualized Technology Investment Cost @ 10% interest rate, NRs/ ton CO2e*

# Study on Demand  Side Energy Efficiency Improvement Potential




| | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| BASE | 369.24 | 396.14 | 433.12 | 477.98 | 535.89 |
| EEST-ALL | 369.24 | 396.14 | 375.38 | 352.73 | 330.91 |




| | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| BASE | 6663.71 | 7432.65 | 8862.85 | 10551.50 | 12865.83 |
| EEST-ALL | 6663.71 | 7432.65 | 7560.24 | 7406.99 | 7210.92 |

- Energy efficiency improvement potential reaches to 38.2% by 2030
- GHG emission reduction by 44.0% in 2030

# Policy Research

## Future Electricity Demand and Hydropower Development Potential in Nepal if it were to transform from LDC to DC by 2022

| | 2020 | 2030 | 2050 |
|---|---|---|---|
| BAU (kWh/capita) | 151 | 391 | 1,348 |
| DCI(kWh/capita) | 279 | 945 | 2,647 |
| BAU(MW) | **2,051** | **5,605** | **23,518** |
| DCI(MW) | **4,325** | **17,726** | **58,905** |

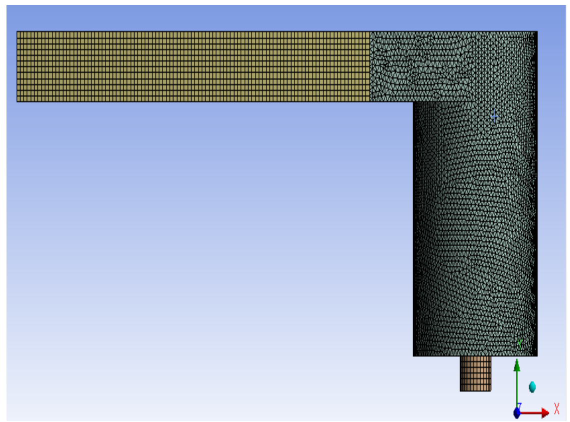
*•DCI: scenario with GDP growth rate at 9.2% (CAGR) as per approach paper for graduation from LDC to DC by 2022, NPC with policy intervention*

- **If Nepal is to transform from LDC to DC by 2022,** domestic requirement of **additional Hydropower Plants**
  - **17,000 MW by 2030**
  - **58,000 MW by 2050.**
- **Foreign Direct Investment possibility ?**
- **Long term Market Security ?**

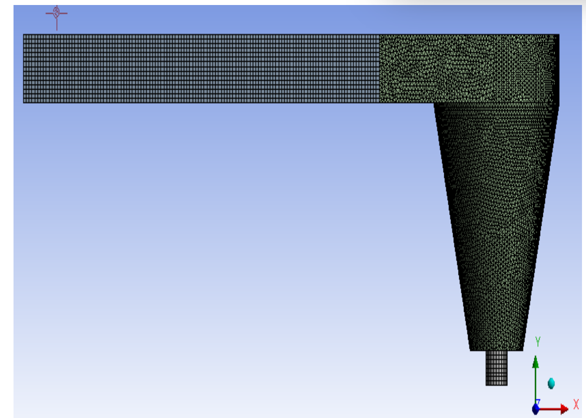
# Comparison of Cylindrical and Conical Basins with Optimum Position of Runner: Gravitational Water Vortex Power Plant

Objective:

To optimize basin for gravitational vortex power plant by computational and experimental approach and to test various runners for maximum power extraction



Computational Domain of Cylindrical Basin



Computational Domain of Conical Basin

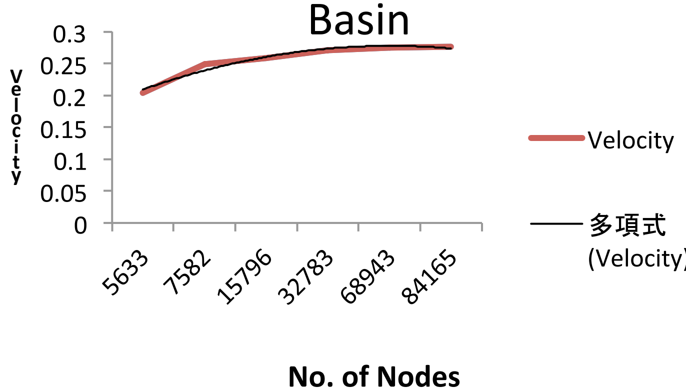
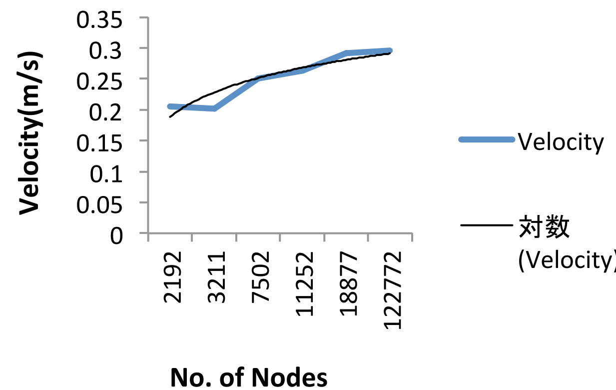
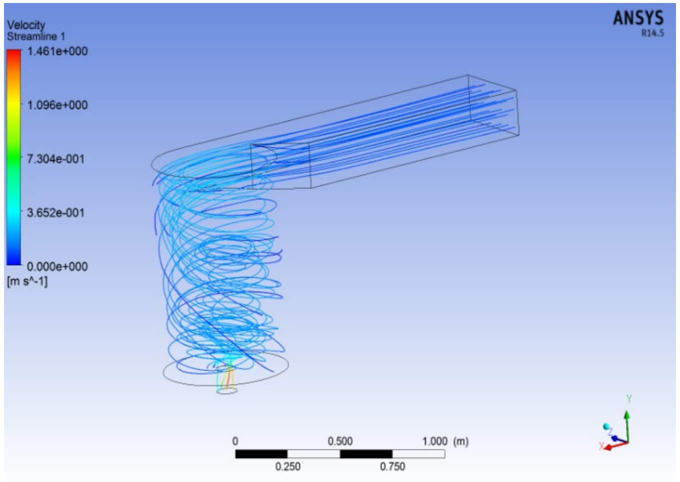



Fig: Grid Convergence for CFD Simulation of Cylindrical Basin

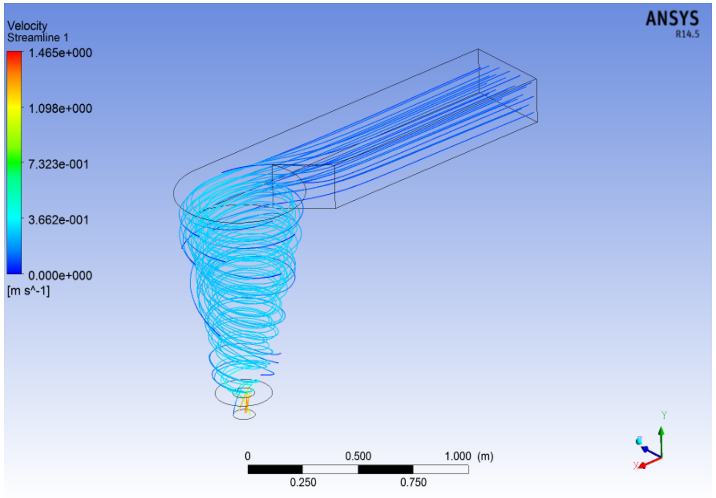



Grid Convergence for CFD Simulation of conical basin

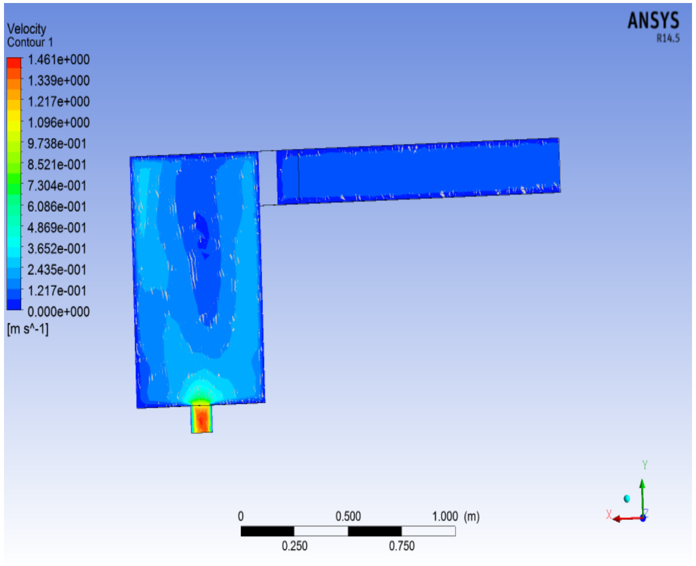
# Results



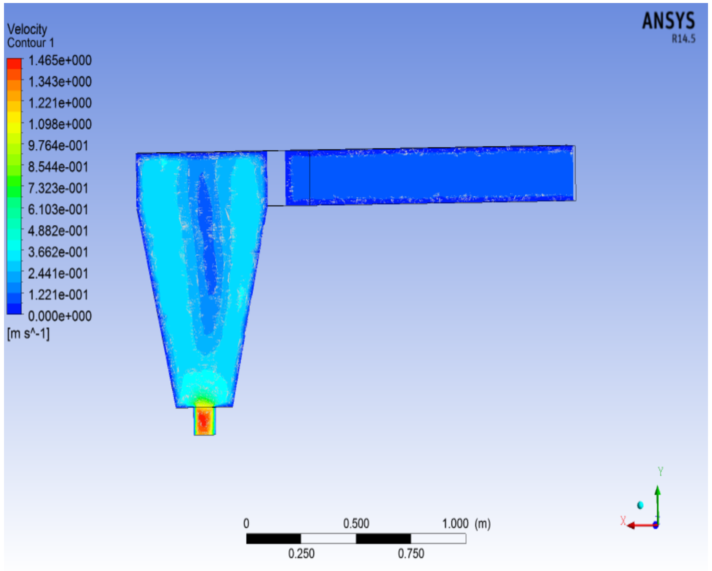

Flow simulation of cylindrical basin




Flow simulation of conical basin



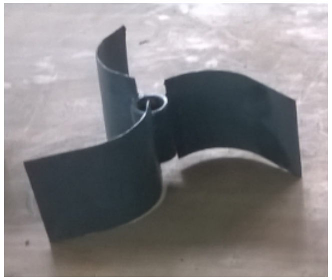

Contour of velocity for cylindrical basin



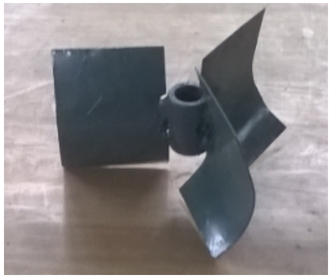

Contour of velocity for conical basin

# Experimental work

Fabricated Scale-Down Model



Model 1 Runner Formulated as Cross flow runner



Model 2 Runner : Formulated as Turgo Turbine

Template for notch angle
And basin opening variation

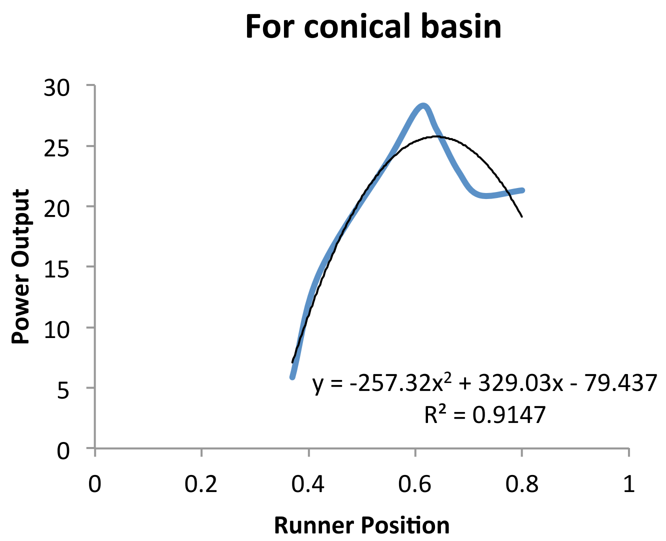
Different basins adjusting mechanism

Model 3 Runner:
Modification of Model 2

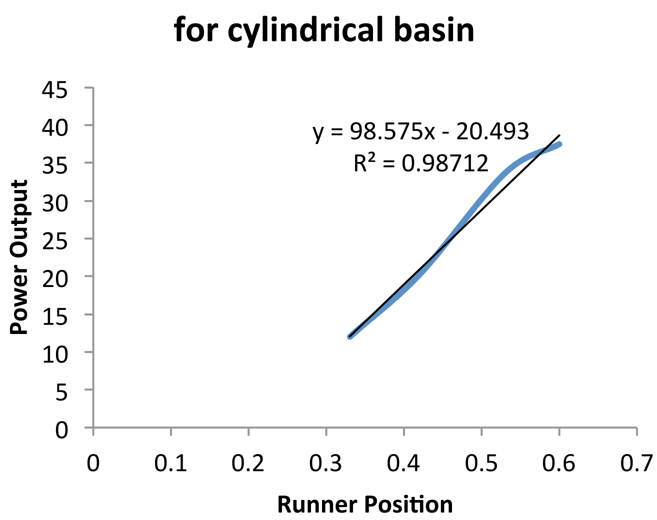
# Experimental Study

| Runner | Torque Measurement | | | Power output | | Power input | | | Efficiency (η% ) | Runner position (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| | $W_1$ | $W_2$ | Torque | ω | $P_{out}$ | Head | Flow rate | $P_{in}$ | | |
| | (kg) | (kg) | (N-m) | (rpm) | (Watt) | (m) | $(m^3/s)$ | (Watt) | | |
| Model 1 | 0.9 | 0.06 | 0.49 | 85 | 4.36 | 0.5 | 0.004 | 19.62 | 22.22 | 0.4 |
| Model 2 | 0.7 | 0.1 | 0.353 | 154 | 5.68 | 0.5 | 0.004 | 19.62 | 28.9 | 0.37 |
| Model 3 | 1.3 | 0.2 | 0.65 | 140 | 9.52 | 0.5 | 0.004 | 19.62 | 48.52 | 0.365 |

Graph of power output / efficiency vs. runner position



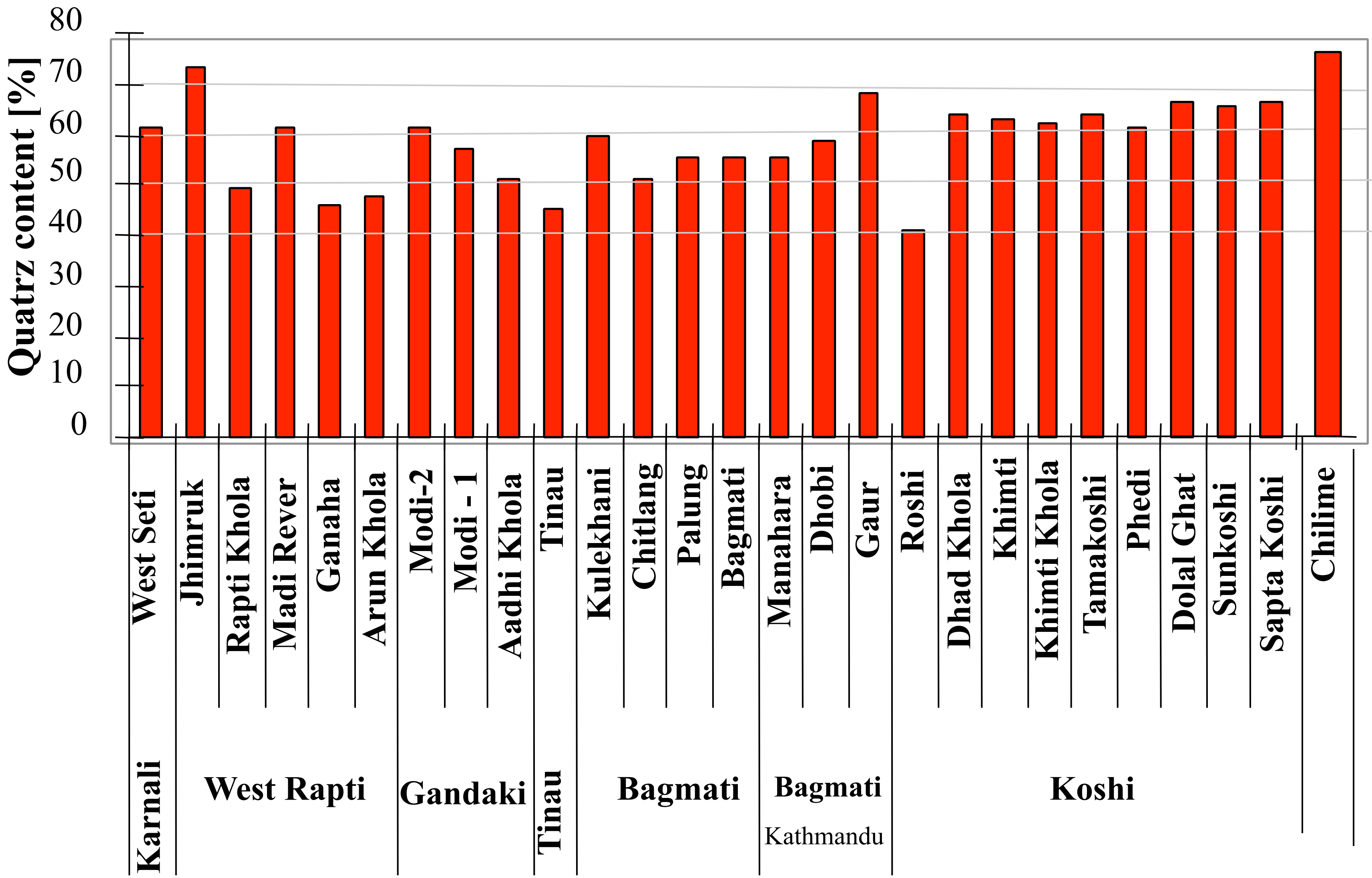

Graph of power output / efficiency vs. runner position




**Conclusion:** Output power, efficiency, vortex strength was found to be maximum in conical basin compared to that of cylindrical basin for all similar inlet and outlet condition. The output power in case of cylindrical basin was found to be maximum at the runner position of 65% - 75% of total height of basin from top position and in case of conical basin runner position had a linear relationship with output power. The output power at the bottom position of cylindrical basin was decreased due to the weak vortex formation in opposite direction to that of the dominant vortex formation. However, there is less effect in case of conical basin and also due to geometric constraints it couldn't be experimentally verified.

# EFFICIENCY DETERIORATION IN PELTON TURBINES DUE TO SAND PARTICLES LED BUCKET EROSION

# Quartz content in Nepali rivers

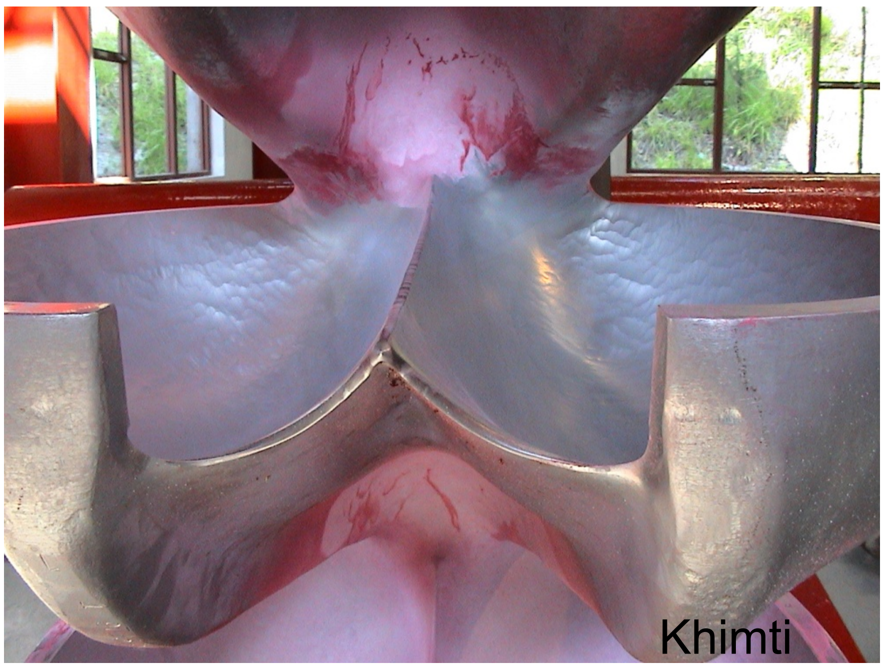



Ref. Kathmandu University, & IOE

| Minerals | Khimti River [ % ] | Khimti Turbine [ % ] | Jhimruk Turbine [ % ] | Hardness Mohr's scale | Special characteristics of the minerals |
|---|---|---|---|---|---|
| Quartz | 62 - 64 | 61 - 63 | 72 | 7 | Hard mineral, resist weathering |
| Feldspar | 3 - 5 | 3 - 5 | 7 | 6 | Gets weathered, white colour |
| Muscovite | 8 - 9 | 6 - 7 | 4 | 2.0 – 2.5 | Light colour soft flaky mineral |
| Biotite | 15 - 16 | 18 - 20 | 3 | 2.5 – 3.0 | Dark colour soft flaky mineral |
| Chlorite | < 1 | < 1 | 5 | 2.0 – 2.5 | Soft flaky mineral, green |
| Phlogopite | | | 9 | | |
| Sillimanite | < 0.5 | < 0.25 | | 6.0 – 7.0 | Colourless, transparent, elongated needle & blade like mineral |
| Magnetite | < 0.5 | 0.5 - 1 | | 3.5 – 5.0 | Shining dark grey, magnetic |
| Hematite/ limonite | < 1 | <0.5 | | 5.0 – 5.5 | Earthy reddish brown iron oxide |
| Ilmenite | Traces | <0.5 | | 5.5 – 6.5 | Shining black/ silver grey |
| Garnet | < 1 | 1 - 2 | | 6.5 – 7.5 | Light pink colure |
| Tourmaline | 0.5 | <1 | | 7.0 – 7.5 | Fragments of black, green, pink |
| Other minor | < 4 | < 4 | | -- | very fine dust particles, clay and other minerals |

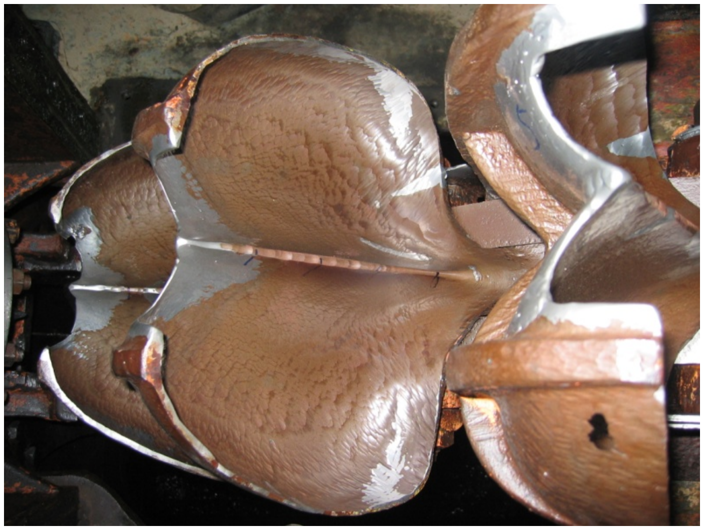
# Wear in Pelton Turbines
## Runner splitter

- Due to erosive wear at high velocity

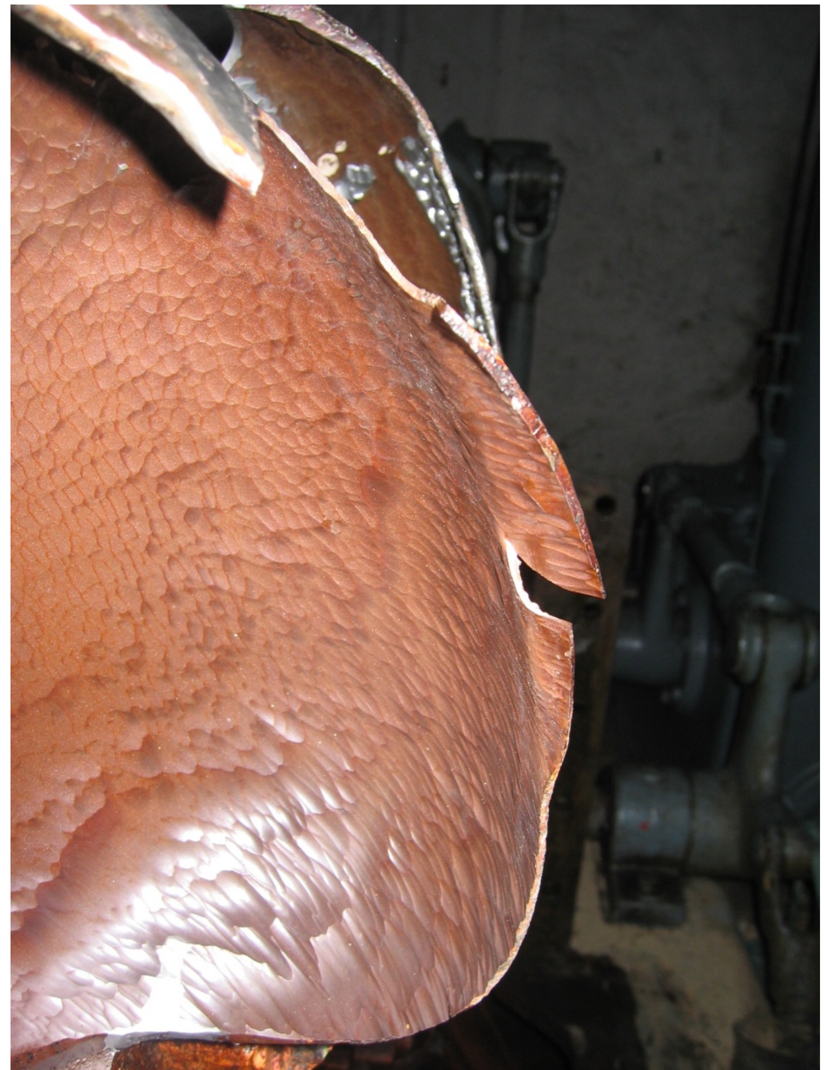



# Sedment erosion in Pelton Turbines

## Bucket Surface



Andhi Khola, April 2004



# 4. Models of Erosion

Truscott (1972):

$$\textit{Erosion} \propto (\textit{Velocity})^n$$

*General Erosion Model:*

***Erosion = f(operating condition, properties of particles, properties of base material)***

# Models of Erosion…

•Bardal (1985) describes the most general formula for pure erosion as:

$$W = K_{mat} K_{env}\, c\, V^{n}\, f(\alpha)$$

*W* is erosion rate (material loss) in mm/year, *K* is material constant and $K_{env}$ is constant depending on environment, *c* is concentration of particles and *f(a)* is function of impingement angle α. *V* is the velocity of particle and *n* is the exponent of velocity.

# Models of Erosion…

Tsuguo (1999): The repair cycle of turbine is determined according to

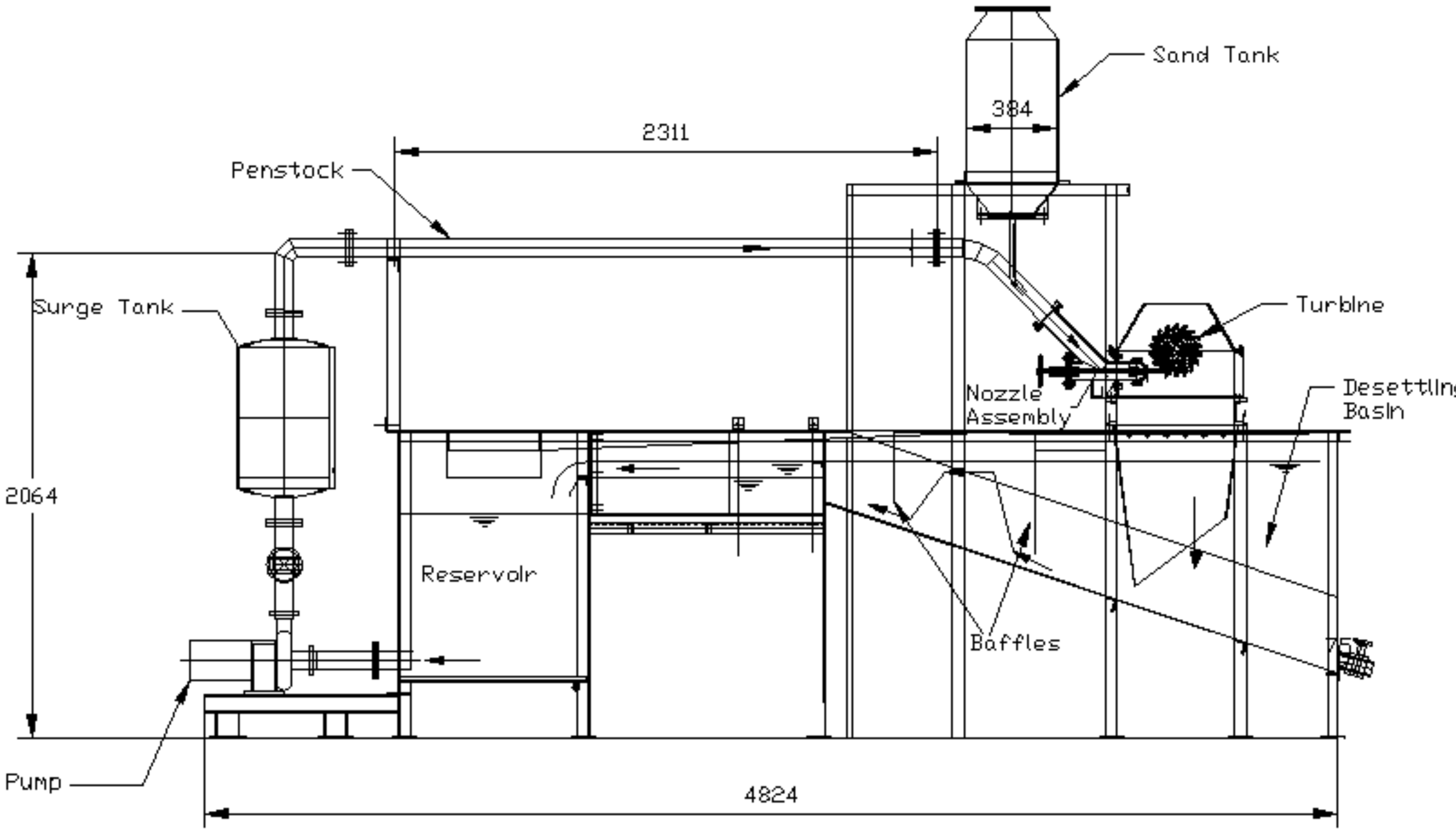
$$W = \beta\, c^x\, a^y\, k_1\, k_2\, k_3\, V^n$$

Where, β is turbine coefficient at eroded part; c is the concentration of suspended sediment, ***V*** is relative velocity. The term *a* is average grain size coefficient on the basis of unit value for grain size 0.05 mm. The terms $k_1$ and $k_2$ are shape and hardness coefficient of sand particles and $k_3$ is abrasion resistant coefficient of material. The *x, y* and *n* are exponent values for concentration, size coefficient and velocity respectively.

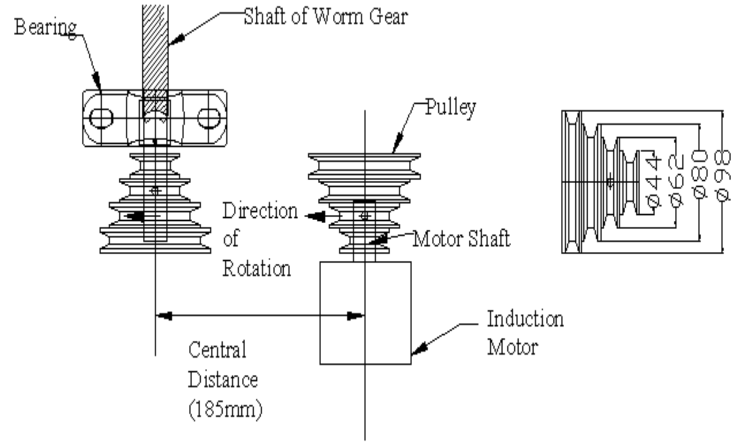
# Objective

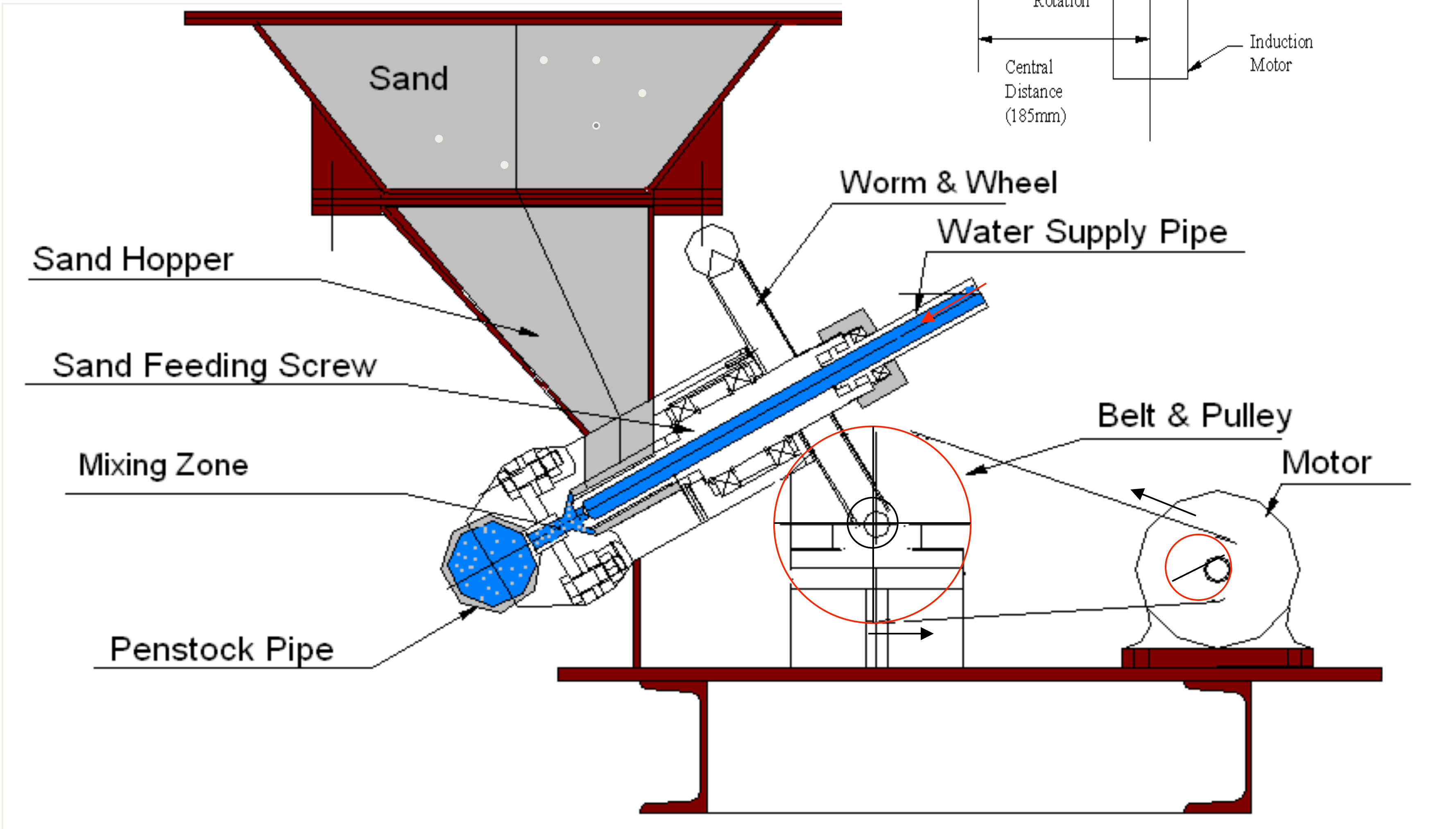
To determine the sand erosion of runner buckets and their effects on the efficiency of Small Pelton Turbines in operation to different parameters

# Design and Development Sand Erosion Test Rig

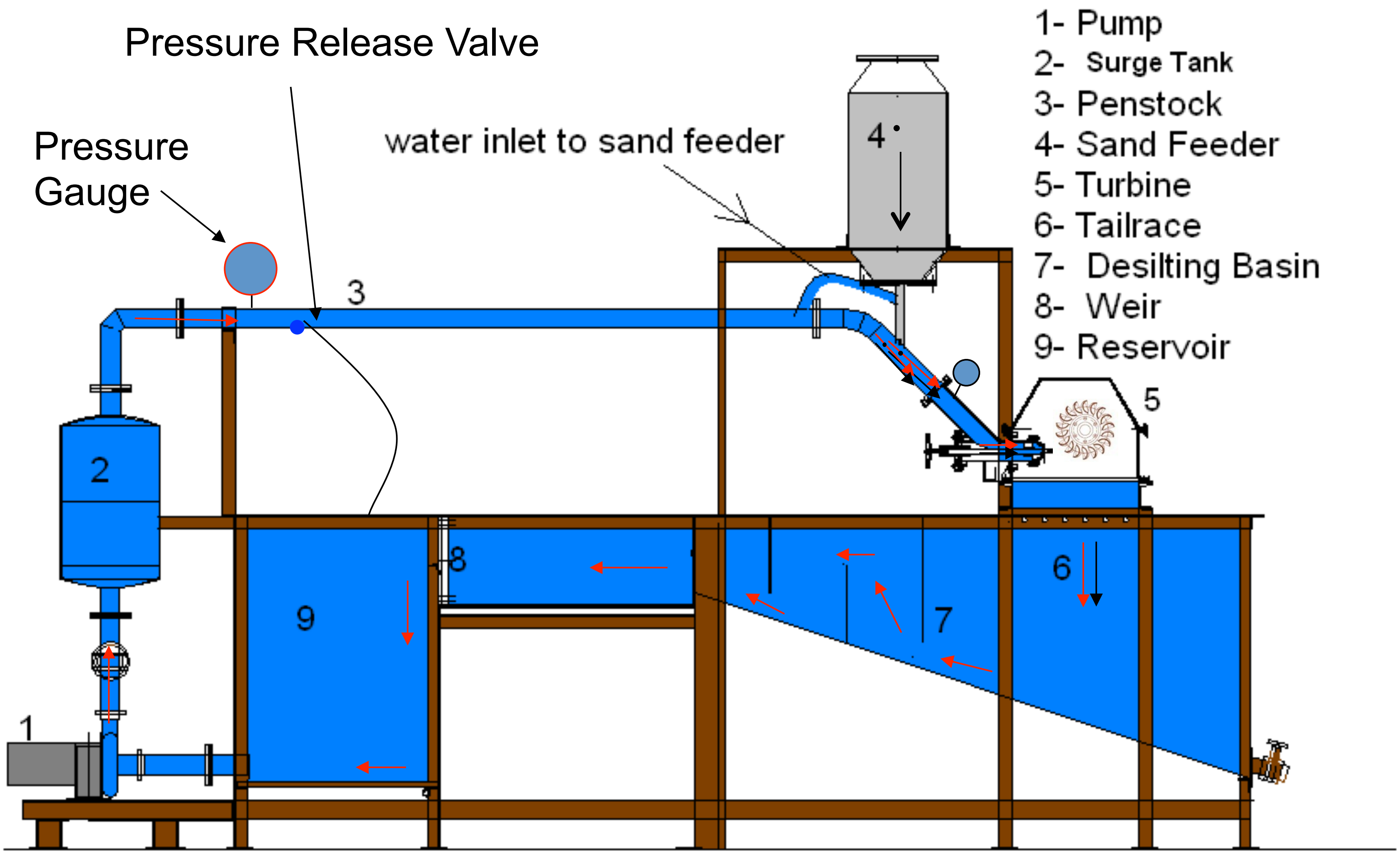


# Sand Feeder Unit



# Test Rig working principle:



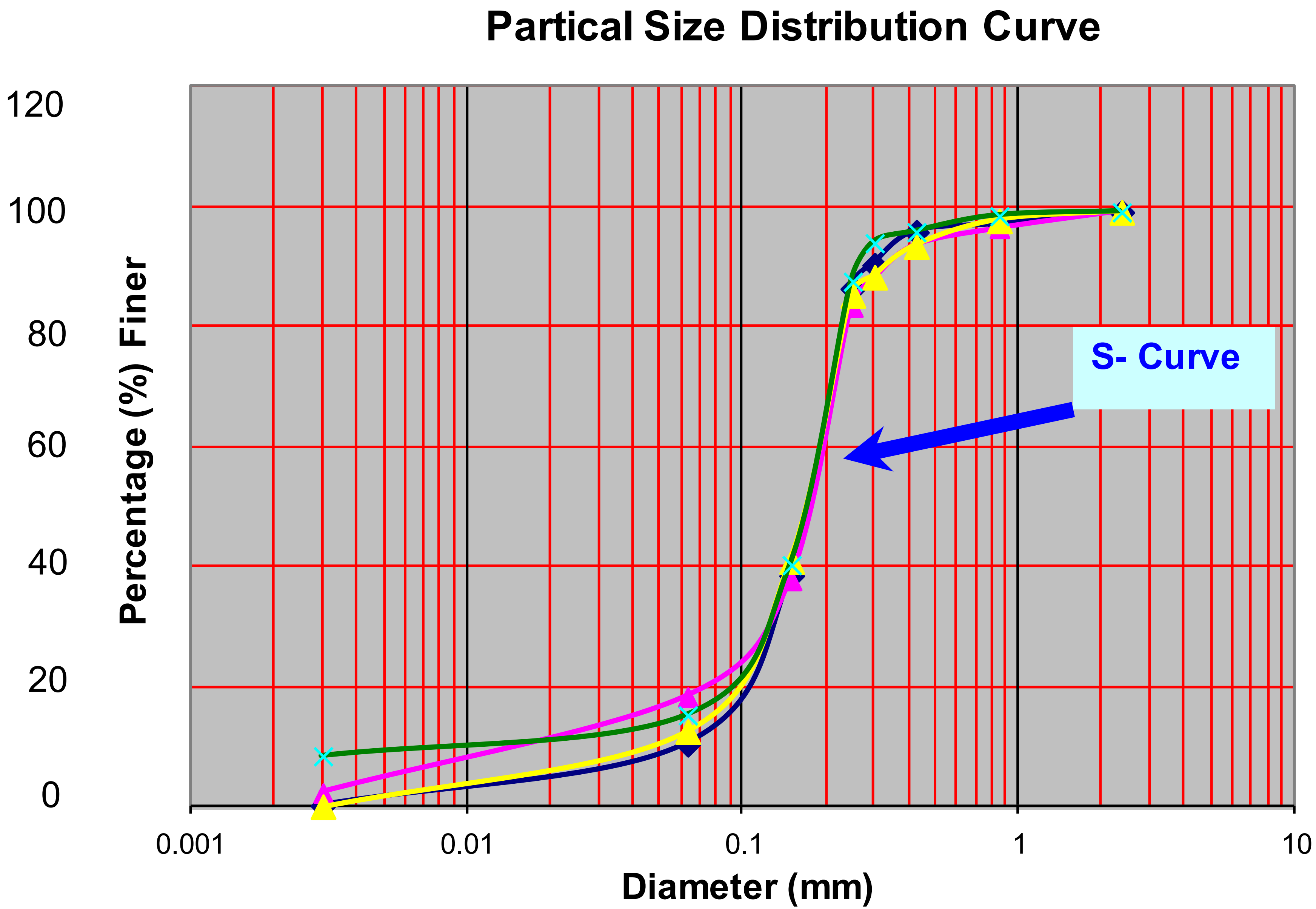
# Sand Erosion Test Lab:


24 4:40PM

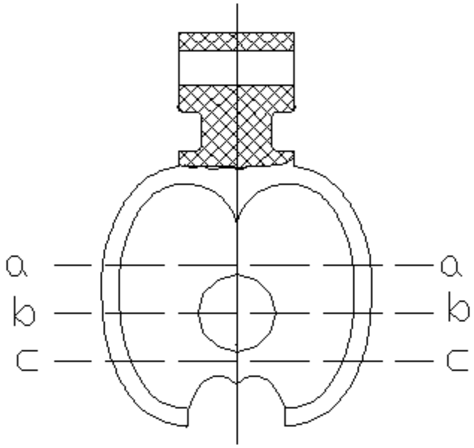

24 4:25PM


27 4:34PM

# S-Curve Development



# Measurement of Bucket/splitter

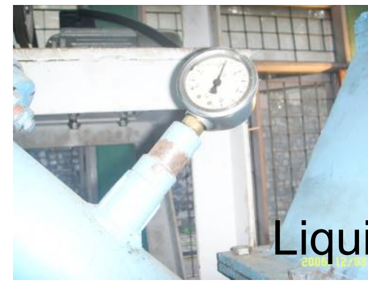





# Continuous Data Logging

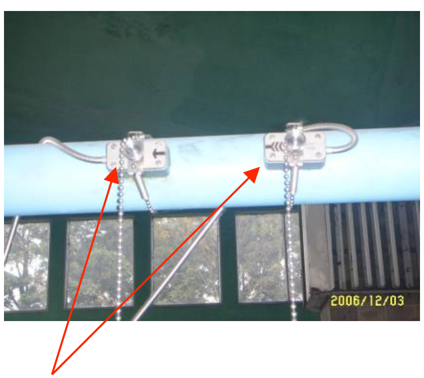
- Pressure Gauges

Vacuum



Liquid filled

- Ultrasonic Flow Meter (UFM)




Transducer


Digital Display Unit

# Continuous Data Logging…

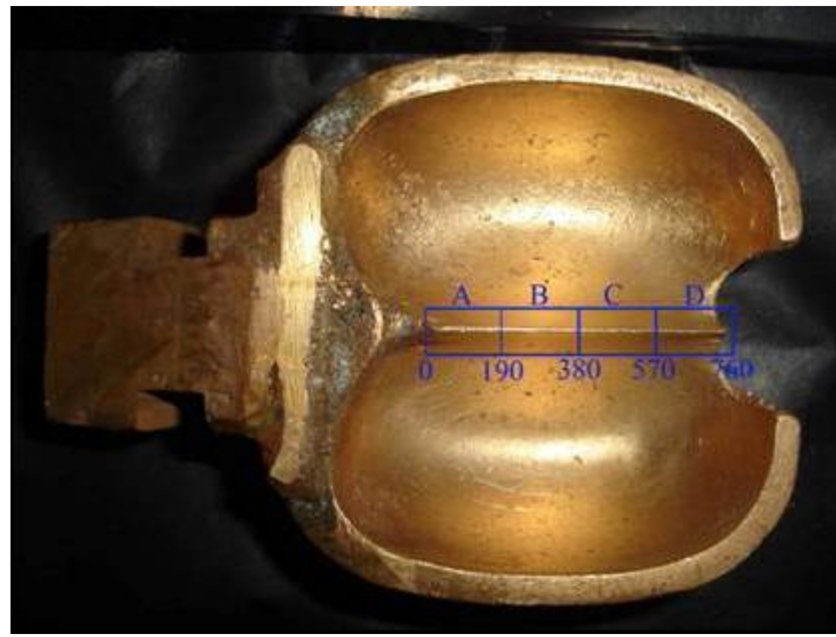
- Rotary Torque Sensor


Rotary Torque Transducer

Display Unit

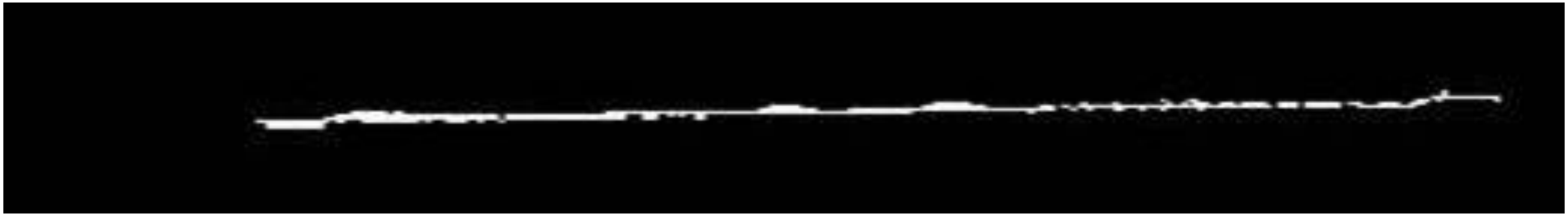
# Splitter width Erosion

- The splitter width was measured precisely and splitter zone were designated by different names. Major comparison was made between widths of pretest and post tests 16 though a systematic comparison was made between each successive test result.

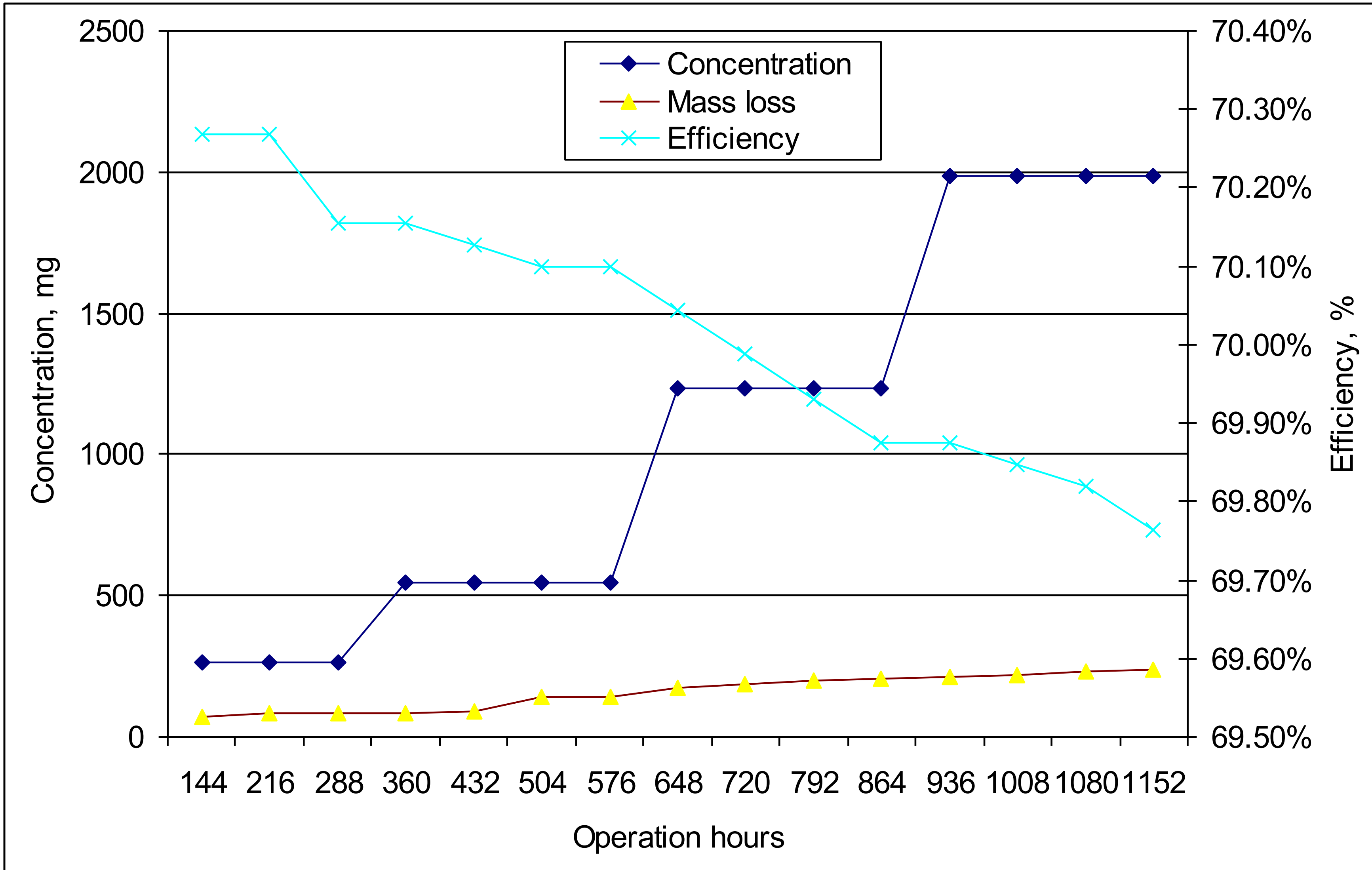


# Histogram equalized and FFT enhanced image of splitter

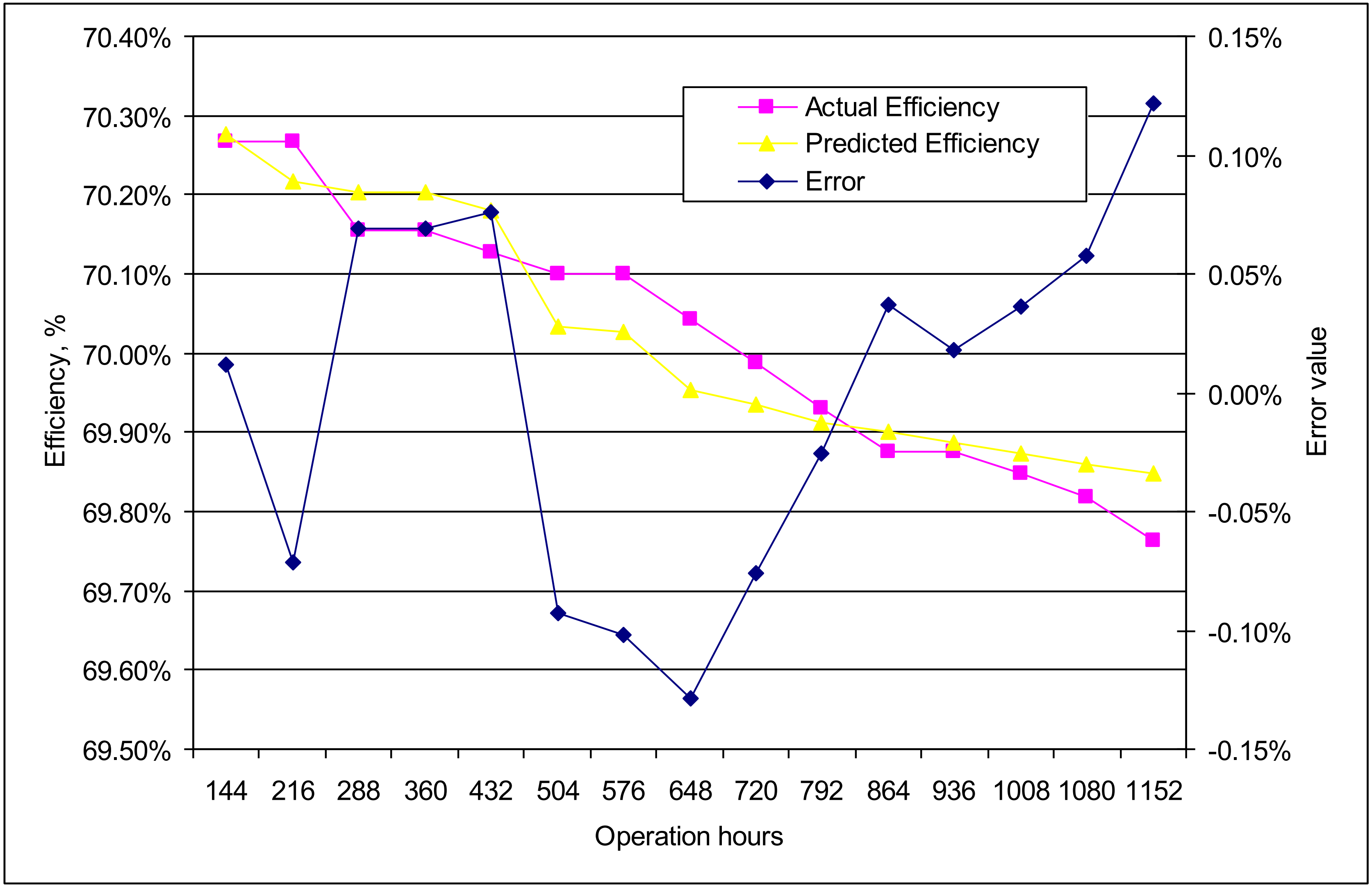
Extracted tips of splitter



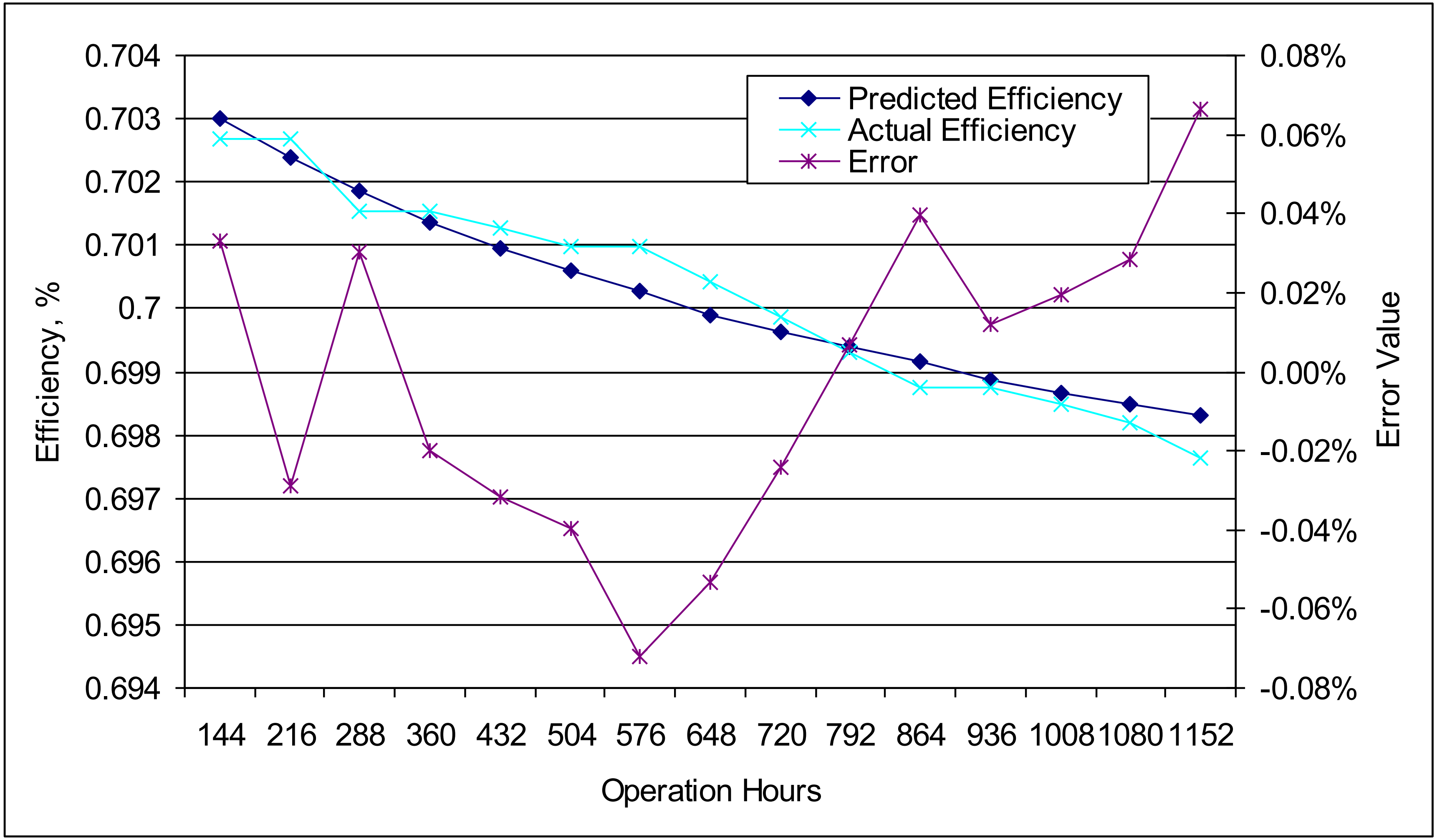
# Efficiency and mass loss with respect to concentration change and operation hours



# This regression model with mass loss has the error value in the range -0.13% to 0.12% with R2 as 0.88



# Error in Efficiency with modified mass loss model



# Efficiency and concentration and operation hours

- Another Regression model is carried out using the concentration and operation hours observed as only variants to predict the Efficiency. The model is as follows:

$$Eff_{wl} = k_4 * C^{-a} * O^{-b}$$

*Where,* $K_4$ = 0.71532869

C = Concentration

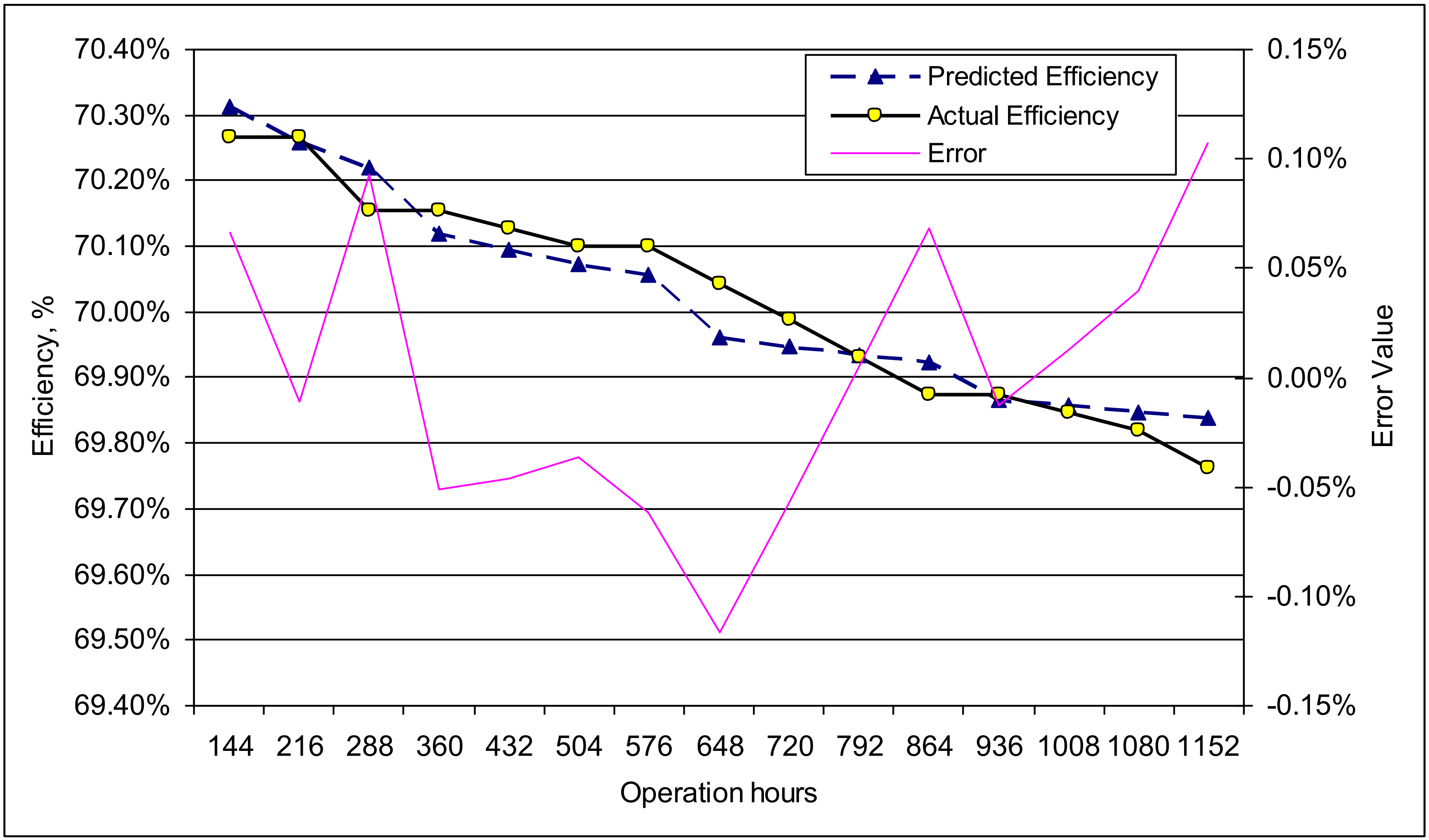
O = operation hour

a = 0.001373259

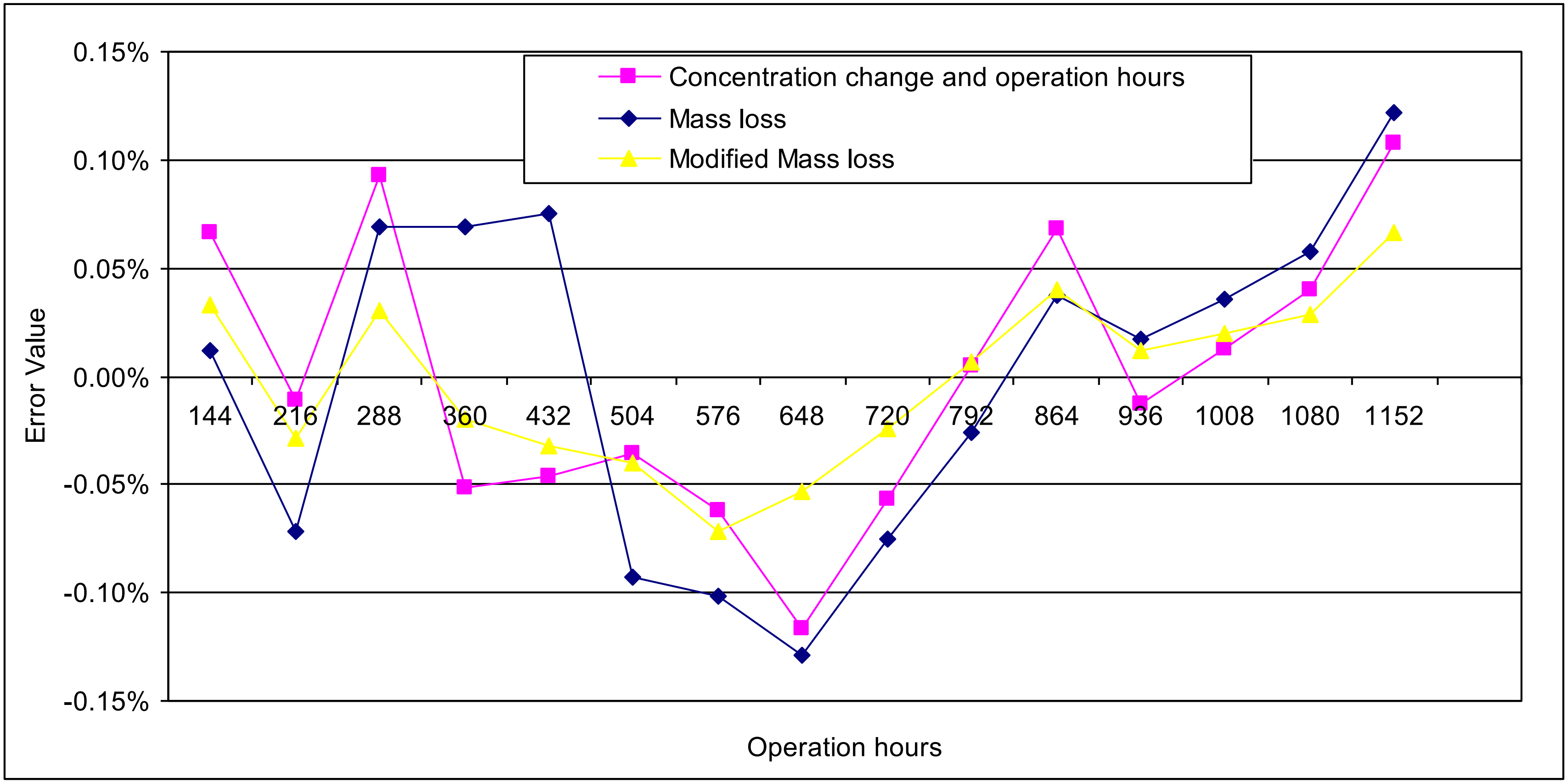
b = 0.001921144

The model (with $R^2$ = 0.92) has an error value variation within the range of -0.12% to 0.11%.

# Error in Efficiency with concentration and operation hours as variants



# Comparison of errors in the Efficiency Models



# Conclusions

- Following main conclusions have been drawn:

  The erosion of Pelton buckets operation with sand laden conditions in terms of mass loss affects the efficiency of turbines.
- The quantifications of efficiency loss can be found by the derived mathematical model, Equation No. 22.
- Where as the efficiency loss with relation to concentration and operation hours the derived mathematical model, Equation No. 23 can be used.

# THANKYOU

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